

RODRIGUEZ

Construction of Grain Elevators

Architectural Engineering

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CONSTRUCTION OF GRAIN ELEVATORS

BY

ROBERTO SEGUNDO RODRIGUEZ

THESIS

For the Degree of Bachelor of Science
in Architectural Engineering

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Roberto Segundo Rodriguez

ENTITLED Construction of Grain Elevators

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Architectural Engineering

W. Clifford Pickett

HEAD OF DEPARTMENT OF Architecture



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Outline of Thesis

- I- The purpose of a grain elevator.
- II- Development of fire-proof grain elevators.
The different types of construction.
- III- Experiments for the determination of the lateral pressures exerted by grain on the bin walls. The various tables and formulas deduced from these experiments.
- IV- Conclusions.

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I

The purpose of the grain elevator.

The ordinary grain bin, or silo, as it is called in Europe, is a receptacle usually having its greatest dimension in its height, designed to receive loose or bulk grain at its top and to discharge the same through an opening in the bottom. The walls of the bin may be built of wood, metal, masonry, tiles or reinforced concrete, according to the requirements.

This elevator or warehouse for grain should be subdivided into small compartments or bins, for various kinds, grades and separate lots of each grain are stored in the same elevator building, each of which it is often desirable to keep separate, or in individual compartments. The smaller the bins, the more closely can the total storage be utilized, since the different lots of grain to be kept separate can be placed in bins that will more closely correspond with the volume of each lot without loss of space. The bottom of the bin usually slope toward ^{the} outlet opening or

spout at such an angle, that the grain runs freely from the bin without leaving any residue.

The bins of an ordinary terminal elevator are supported on a heavy framed structure at a sufficient height to allow loaded cars to be brought beneath them and to pass through the building. The operation of receiving grain from either cars or vessels is practically the same in all elevators. In railroad elevators, the cars are delivered to the elevator and handled by car pulling mechanism, placing the cars in the building opposite the elevator legs. These elevating machines, or legs, consist of a belt carrying buckets between a large pulley placed at the highest point of the elevator and a foot pulley placed at the lowest point of the elevator, which is ordinarily ten or twelve feet below the back to back. The grain is usually elevated at first sufficiently to enable it to reach a destination in the bins by gravity. The cars are unloaded by power car shovels, each operated by one man, who carries a scoop at the end of the shovel rope, back into the car. When he drops and shifts

the upper, the mechanism of the elevator
pulls him with his scoop and its load of
grain to the car side where it stops auto-
matically. The grain falls into the wide
open hopper, or dump, built around the
elevator leg, the outlet of which is directly
into the elevator buckets. From the top
of the leg it discharges by passing through
the ganners and scales, where it is weighed
usually in draughts of a car load, and
is then spouted or run by horizontal con-
veyors to the bins to be occupied. When
the grain is received from the bins, it
is drawn from the lower outlet and ei-
ther spouted or conveyed to the elevator
leg, re-elevated to the top of the building,
where it can be again weighed before ship-
ment, or it is sent direct to the other compart-
ments in the building. If the grain is to
be shipped by car it is dropped through
a spout from such an altitude that the
force of the fall will completely fill both
ends of the car simultaneously.

The operation of loading a car with 80,000 lbs.
of grain will take five to ten minutes.
The same car could be unloaded in from



seven to fifteen minutes. When shipped in vessels by water, the grain falls from the deck through suitable chipping spouts located on the outside of the building and reaching to the hatch, into which it can be delivered at the rate of 15,000 to 20,000 bushels per hour for each spout.

In many elevator buildings the grain is treated and its quality is improved by special cleaning, polishing, grading and drying machines. Where grain is received from vessels in an elevator, a specially constructed elevator leg, called a "marine leg," is used. This is equipped with means for placing the leg in any hatch in the vessel and raising or lowering it as the conditions of unloading may require, delivering the grain inside of the building. This is a brief description of the modern grain elevator.

The quantity of grain to be handled in a given time, and the required capacity for storage, determine the style, shape and size of the elevator building. If the handling capacity be small, compared with the capacity for storage, the bins will

occupy too much area for the leg. to
 fill them by direct spotting, in which
 case conveyors are used both above &
 below the bins, from and to the elevator
 leg. for filling and emptying the storage
 bins.

II

Development of the Fire Proof Grain Elevator.

The evolution from the farmer's granary, and the loft filled with sacks of grain, to the modern elevator with its storage capacity of a million bushels or more with its wonder-working machinery, has for a long time been considered one of the marvels of the world. As far as the present of the mind with confidence. Before 1865, the wooden elevator had been developed almost to the condition in which we see it to day in some of the large grain handling markets. These structures were sometimes enclosed by brick walls or were covered with sheet metal. The bins are made with solid walls of wood six inches thick, built by nailing 2"x6" planks on top of each other, breaking joints at the angles and intersections. They form a nest like pigeon holes set on end. These bins are generally set in very heavy groups.

7
-ed wooden posts, rarely on iron columns, and they require very massive foundations. Railroad tracks are laid between the posts, and at one end of each elevator is the boiler and power house with its high brick smoke stack. On top of the elevator is what is called the cap, a long and narrow structure, which contains the machinery for lifting and lowering the grain.

Such a structure is one of the most uncomfortable and dangerous of inventions from the point of view of fire safety, ever conceived by man, yet some persons have claimed for the last thirty years, that it is not capable of improvement in that or any other respect, except in small details, such as mechanical operation.

In 1865 the late George H. Johnson was, and had been for many years, a draftsman for the "Architectural Iron Works" of New York. In the course of his duties, he had frequent occasion to visit Chicago to supervise the casting of some cast iron fronts for buildings.



His attention was thus attracted to the operation of the Chicago grain elevator, at that time the largest in the United States, and to the dangers as fire risks.

Realizing that these immense wooden structures could not be erected in the closely built eastern cities on account of their causing great danger to contiguous property, Mr. Johnson determined to induce some person to erect an iron elevator in the east, where grain was handled very awkwardly and expensively, in contrast with the more elevating machinery used in the middle west. The result was that in 1855 two iron elevators were built from his plans, one at Brooklyn, N. Y., for the United States Warehouse Co., and the other for the Pennsylvania R.R. at Philadelphia. Before this time that iron, being uncombined, was at that time regarded as a flammable material.

At first these iron bins were considered by all other elevator interests as a novelty, who claimed that the grain would ^{heat} and become damaged. But ultimately,

they proved not detrimental to the grain and iron elevators have been successful ever since.

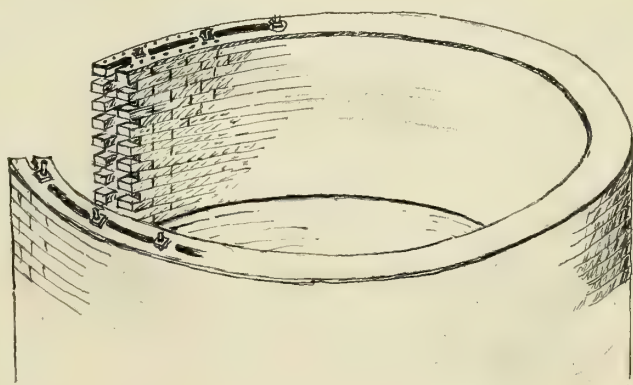
Soon after the erection of these iron elevators, being convinced that clay was to be the future material, Mr. Johnson, proceeded to design a grain storage house entirely built of brick, and bent his energies toward accomplishing it. After several years of effort, the Tipton Grain Elevator in Tipton, Iowa, was erected, and as a result the famous Tipton elevator in that city, was erected in 1869. The sketch shows the construction of the brick bins. This

elevator has no external wall above

the ground story; the exposed exterior of the bins forming a corrugated surface. In

addition to the brick tanks the

interstices between them were used as bins, so that the whole structure could be fitted solid. The walls are ten inches thick, being of two courses of brick with



FIRST FIRE-PROOF GRAIN BIN
BUILT by Mr. Johnson

2" air space between them. If in the case of eighteen courses in height, the walls are constructed with cast-iron bond plates which are bolted together horizontally. Each course of bond plates is bolted to the next course both above and below with vertical iron rods in the air space around each circle and distant from each other about twenty inches. This building was the only fire-proof granular elevator prior to 1890.

In 1878, Mr. Johnson built the elevator of Minnetonka, Minn. & Co.'s wooden elevator at Archer Ave. and South Branch, Chicago, of hollow tiles. He also constructed the first hollow-tile floor arches in Chicago in 1879. I give this last information not because it appertains to the subject before me in this thesis, but because it is of great interest in the history of the development of fire-proof construction.

In 1899, E. V. Johnson, son of Mr. G. W. Johnson, with the assistance of James L. Record, of Minneapolis, and Horace B. Camp, of Akron, Ohio, built a single bin on the grounds of the Osborne. He

Millen Elevator Co., and presented it to the company to use as a demonstration. This bin was 20 ft. in diameter and 60 feet high, which afforded a capacity of 20,000 bushels. It was erected in extremely cold weather and was allowed to be only thirty days before it was filled. It was built of 2 1/2 inch thick brick, 12 inch long, in two courses, with one inch of gravel between, which made the wall 5 1/2 inch thick. The bin was secured by steel bands varying in section from 2 x 3/16 inch to 2 x 1/8 inch, and 7 x 1/2 inch solid tiles were used as binders.

Everything being satisfactory to the inventor, The Barnett's Record Co. of Minneapolis, assumed all responsibilities of contractors, fully guaranteeing these bins, and in less than a year from the time of the first test, it was erecting four bins of great size for J. C. Taylor's Great Eastern Elevator, at Minneapolis. This company has since erected a large number of these tile bins.

I think enough has been said.

give a good idea of the development of hollow tile construction of grain bins and elevators.

For a good understanding of the construction of the tile elevator, as built by the Summit Elevator Co., see blue prints & photographs, the last pages of this thesis.

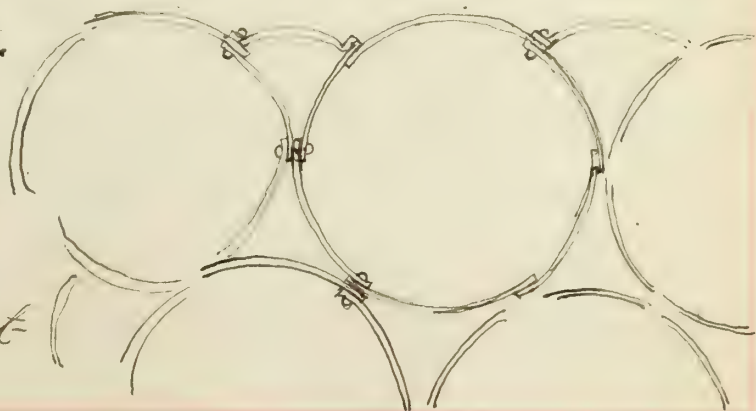
In the following pages the steel and reinforced concrete elevator is discussed more in detail.

Steel Bin Elevators

The use of steel in the construction of grain bins has already been mentioned. The sketch shows the method of constructing steel bins used by Mr. Jas. Macdonald, a grain elevator engineer of Chicago. Generally the first story and foundation of these buildings are of concrete.

Mr. Macdonald speaks as follows of the steel bins:

"The steel construct



ion has the advantage of being the lightest structural material per bushel of storage, it has great flexibility in case of rearrangement, can be used in all seasons and places, and for all practical purposes it is fire-proof. But steel has been subject to great variations in cost, it requires more or less care in its preservation from rust on exposed surfaces, and it might be damaged by fire, if built adjacent to an inflammable building, unless covered with protecting walls of masonry.

"There is one advantage, however, in a steel elevator building not found in any others, it may, at any time, be taken down and removed without greatly reducing its value. Many elevators in the heart of the city of Chicago have outlived their usefulness, or business has left them, and the ground occupied by them has become too valuable for other purposes to be profitably utilized by the grain trade. They can be economically removed only by fire, and this condition should in the future attach

to a steel elevator, this may be taken down, loaded on cars, and transferred to a new location with small loss in value."

"Reinforced Concrete Elevators."

The reinforced concrete has not been used very much for the erection of grain elevators in this continent, although, in my opinion is the most suitable material for this kind of structures. A careful discussion of the reinforced concrete elevator will be found in the last part of this thesis, which data was translated from the German by Prof. N. C. Kicker.

A few reinforced concrete elevators have, however, been built in this continent. Of all of them the most interesting one, from a structural point of view, is one designed and built by Mr. Jamieson, the author of a series of experiments which will be discussed later. A description of this structure is given on the next page.

This elevator is of great interest for two reasons. First, because it shows that the engineering

This continent are superior to any reinforced concrete in the construction of such structures, thus showing that they begin to realize the suitability of this material for the construction of grain bins; and second because it is the first reinforced concrete structure on this continent, where the grain rests on columns and not directly on the ground. The bottom hoppers hang from girders resting on reinforced concrete columns.

The Following is taken from the Engineering News. June 23-1904

Design for Reinforced Concrete Bins for Grain Elevators.

Reinforced concrete grain elevators have been built in Europe for more than 20 years and they at present practically the only form of fireproof elevator construction that is employed abroad. The usual practice is to make the bins rectangular and to support them on concrete steel columns resting on either separate or continuous footings of concrete. As good examples we may mention the 1,200,000-bushel elevator at Genoa, Italy, with 10×14 -ft. bins 57 ft. high, and the Dunstone-on-Tyne elevator in England with 14×14 -ft. bins 60 ft. high. In America there have been only a few grain elevator bins built of reinforced concrete and these have all been cylindrical with their bottoms resting directly on the ground and with conveyor tunnels underneath. Recently, however, American elevator designers have turned their attention toward

developing a rectangular bin construction with supporting columns. One of the most notable of the designs which have been so developed is shown on the accompanying drawing.

The drawings illustrate the main frame or working or working floor structure, the bin hopper bottom, and the bin wall construction of the type of elevator known as a terminal working elevator, at which the work to be done consists in unloading cars, cleaning and mixing grain, and loading vessels. To understand thoroughly the significance of the construction illustrated it is necessary to know the structural characteristics of the type of elevator designated.

This class of elevator requires a working floor above having a clear height of 20 ft. between the bottom of the bin and the level of the rail car track, low of which usually run through the house to permit the car to be loaded directly into the elevator legs. On this floor the car unloading and mixing machinery, the cleaning machine, etc., are also

headed. To give the upper head room
 with hopper bottom bins the columns
 must have a length of about 35 ft. from
 floor level to underside of girders. The
 spacing of the columns has to be such as
 to give sufficient room for the cars
 and also to permit the legs to be spaced
 so that the doors of a line of coupled
 cars will come approximately opposite
 each leg. The best width of a building
 of this type is seven bays or approximately
 150 ft., and for a million bushel
 storage capacity the length would be
 14 bays or 100 ft. The bins employed are
 usually 75 ft. deep and 17 ft. square
 and on top of them comes a grain-truck
 cupola set over the three center rows of
 bins and running the full length of
 the building. In the cupola all the
 work of the distributing of the grain
 is done.

The reinforced concrete construction
 illustrated meets the structural conditions
 just outlined. Its original and promi-
 nent features are the columns, the bin
 hopper bottoms and the bin walls, and

there have been worked out by J. A. Jamieson, Consulting Engineer, of Montreal, Canada, who has patented the bin bottom and the bin wall construction in the United States and Great Britain, and has applications for patents pending or partly allowed in Canada and some of the European countries. The drawings are to a great degree self-explanatory. They comprise a sectional plan and sectional elevations of the bins and details of the column and girder construction.

The first feature of note in the column construction is the well defined flange. This is the proposed construction which has already become prominent through the publications of Mr. Jamieson. The important thing to be noted, however, is that this type of reinforcement was independently evolved by Mr. Jamieson. See letter to Mr. Jamieson, page 1.

"The principle of the column is of original design by the writer, my experiments in this direction first starting about three years ago, and being based on the known manner in which a concrete prism fails.

when used in construction. I first tested steel tubes filled with concrete, in which the tube acted as a binder against the swelling and bursting out of the concrete; next I tested steel rods tied to steel rods so that the steel would be protected by being fully embedded in the concrete, and, finally, the spiral reinforcement was adopted. Before I had my tests completed, however, I was forestalled by the publication of Considère's tests which he had been conducting concurrently or slightly in advance of mine in their latest shape."

The column construction is made entirely clear by the drawings. These columns support two sets of girders at right angles to each other. As will be seen these girders so bond into the bin bottoms as to form a sort of "T" section, and are continuous with the vertical bin walls. Their reinforcement consists of two straight and three "curved" bars, and the straight bars reach into the columns and are bent up as is at times to give a mechanical bond.

The bin bottoms are reinforced by two

series of rods intersecting at right angles. Each rod, with the exception of the four at the center of each series, forms a complete turn across the two bottom and deck beams, bent over the bulkhead beam, set over the supporting girders.

The two sets of rods intersect each other at the corners so that, starting at the ends of the beam, the part of the rods running down on the angle is of 75° or 90° depending on the angle while the horizontal part is of decreasing length at points of intersection. The horizontal part is preferably carried under the part on the angle, since the parts running down on the angle must take all the strain due to vertical load while the horizontal parts act as the tension members of the triangular concrete slab in which they are assisted by the angle parts in proportion to their distance from their neutral center. The strain on the ends of the bars where they bend over the deck beams is very high since the required amount of steel is governed

by the reinforcement necessary to give the requisite strength to the slab.

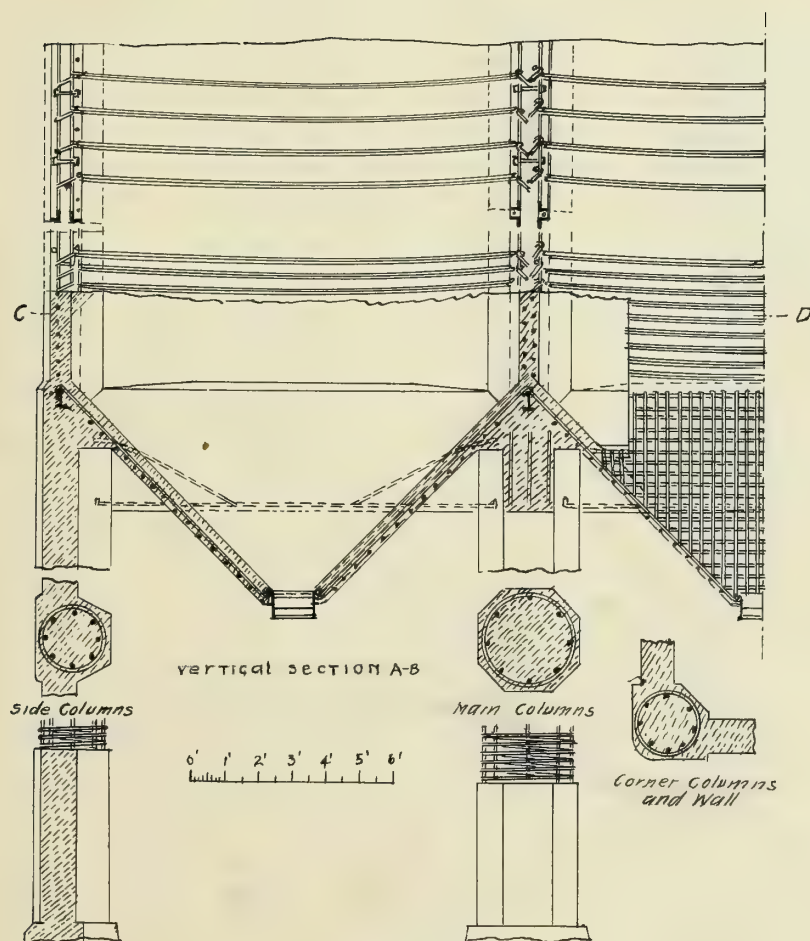
In reference to this form of bottom construction, Mr. Jamieson claims that not only is a fire resistant construction obtained, but one which is exceptionally strong and stiff and one which can be built for approximately half the cost of a bottom built of steel plates which bulge very badly when loaded. Mr. Jamieson has had this type of construction of bin bottom in practical use for over a year in bins 14 ft. square 60 ft. deep and there is not yet a visible crack, and when the bins are loaded there is practically no measurable deflection.

The bin wall reinforcement consists of a series of horizontally disposed wall rods fastened by hooked ends to vertical angles set directly over the main building columns. These vertical angles are arranged in sets of three or four, the angles of each set being spaced and connected by bolts and punched with holes to receive the ends of the wall rods. These take the tensile stresses due to the resultant

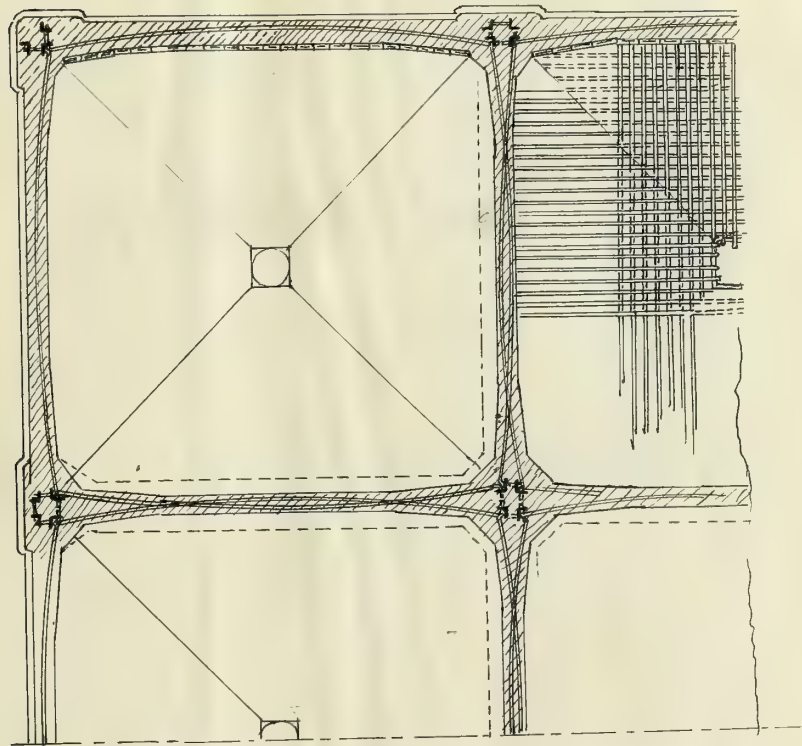
grain pressure, and are curved to an arc with the ends bent to such an angle that when hooked into the vertical supports they lie at an angle to both the vertical and horizontal, thus providing for the horizontal pressure and assisting to carry the vertical load into the greater area or thickness of concrete formed by the wall intersections which were built over the main columns. The interior walls require only one set of rods, while the exterior walls have two sets to resist the pressure due to the grain in either of the two bins between which they form the dividing walls. The sections of the concrete in the bin walls and in the hopper bottoms are clearly shown by the drawings. It may be noted here also that the bin bottoms in the design illustrated have a factor of safety of $6\frac{1}{2}$ and the bin walls have a factor of safety of 6 for the horizontal pressure, and of 7 for the vertical load, or a maximum load on the concrete at the bottom of the wall of 310 lbs./sq. in.

To the information from which the

criptions have been prepared, and are included
in the text. The names of the
persons of the collection are given.



DRAWINGS ILLUSTRATING ELEVATOR SHAFT
BY MR. J. J. JONES



Part Sectional Plan Through C.D.

III

Grain Pressures in Deep Bins

Preliminary discussion

The comparatively recent change made in the structural materials of grain storage bins, or silos, has caused the question of grain pressure to become one of great importance at the present time.

Until quite recently, practically all grain elevators on this continent were built of wood, the storage bin being laminated or crib construction, a number of walls extending both longitudinally and transversely through the building. These walls were constructed of planks 2 inches thick, laid flat and spiked on each other, being from 4 to 12 inches wide, according to the quality of the material and the size of bin required. The width of planks or the thickness of walls was decreased towards the top, and the walls were spaced 12 to 14 ft. apart in both directions, thus subdividing the storage

space into deep bins 12 to 14 feet square and 50 to 70 feet deep.

So long as this system of construction and size of bin was retained, there was no great need of accurate knowledge of the lateral pressures produced by grain since the thickness and strength of the walls could safely resist the lateral pressure, and safe resistance of the hopper bottoms of the bins under the vertical load had been well established by practice. Further, with a wooden bin wall of sufficient strength for the lateral pressure, the wall had an ample area as a column to carry the vertical load transmitted to it by the friction of the grain against it. This form of construction has been in use practically from the invention of the grain bin system on this continent, and in many respects it is admirably adapted to the purpose.

The defect, from a structural point of view, was its lack of vertical rigidity, by reason of the shrinkage of the wood and the compressing of the many horizontal joints during the first filling of the bins,

which usually causes a settlement of 12 to 18 inches in 20 feet, thus necessitating that very great care should be taken to distribute the grain load uniformly when first filling the bins, in order to prevent deformation and unequal stresses in the structure. When, however, the initial settlement has occurred, no further precautions are necessary.

The chief defect, however, of the wooden elevator is its liability to destruction by fire, causing a heavy loss on the building and its contents, and therefore requiring the payment of high insurance premiums. The increasing value of insurance and of lumber, combined with great inconvenience and loss of business to transportation companies by the destruction of an important terminal elevator, created a sudden demand for fire proof buildings; the resultant change in the materials of construction made necessary a more accurate knowledge of grain pressure under all working conditions, in order to permit the intelligent designing of bins of any desired material or of increased diameter and depth.

Experiments.

Before the year of 1900, experiments had been made in Great Britain, by Isaac Roberts* in 1882, in Germany, by H. A. Janssen in 1895, and by Mr. Froude a year later, in order to obtain a definite knowledge of the pressures produced by grain in deep bins. None of these experiments, however, had been carried out in a satisfactory manner, or had supplied sufficient data for enabling the engineer to make an economical and reliable design of a grain bin.

At the beginning of the year of 1900, Mr. J. A. Jamieson,* Elevator Engineer of Montreal, Canada, began work on a series of experiments. The first difficulty he had to overcome was to design an apparatus suitable for making the tests. After several styles of weight scale levers and beams were designed and rejected, because subject to serious objections, Mr. Jamieson conceived the idea of using a hydraulic diaphragm and a mercury or water column gauge, the former being placed

* See Eng. News, March 10 - 1907, page 237.

inside the bin at any given point of the sides or bottom, with a tube leading through a small hole in the wall to the gauge, therefore enabling him to ascertain the pressure per square inch either vertically or laterally at any point inside the bin. This appliance was immediately designed, care being taken to get the pressure face of the diaphragm, made of pure sheet rubber, as large as practicable, so that there would be no appreciable receding of the face by displacement of the water, owing to the pressure raising the mercury in the small gauge glass. When this appliance was constructed and tested, it was found to be an accurate and sensitive instrument for measuring the pressure. See fig. 1 page 28

On April 10th, 1900 and successive days, the tests were carried out in the full sized bins of the Canadian Pacific Ry. elevator at West St. John, N. B., the inside dimensions of the bin being 12 ft. by 13 ft. 6 ins., and the depth above the hopper bottom, 67 ft. 6 ins; The grain used was Manitoba wheat, weighing 49 lbs. per cub. ft.

The hopper bottom of the bin was first

filled with grain and leveled off. To obtain the lateral pressure the diaphragms were then placed in position against the walls a short distance above the hopper bottom, with the face vertical; to obtain the vertical pressure they were placed above a small platform attached to the hopper bottom, with face horizontal.

The gauges were set up in an adjoining bin, a small rubber tube forming the connection between the diaphragm and the mercury cup of the gauge, the diaphragm and tube being completely filled with water. The grain was then weighed and run into the bin in the usual manner; the first draft having a clear drop of 70 ft. Each draft weighed 30,000 lbs. and occupied a depth of 3 ft. 9 in. in the bin. The gauge was closely observed as the grain was running in, and the maximum reading taken and recorded as each draft was received, until the bin was filled. The gauges and the grain were then allowed to remain for about 18 hours, while practically no change occurred in the reading of the gauge. The grain was then drawn out of the bin and

the gauge was closely observed and the readings recorded as each 30 000 lbs. were drawn out, the maximum readings during the draft being taken. The bin was emptied at the rate of 9,000 bushels per hour. The pressures fluctuated considerably as the grain was being removed, with a maximum increase of 4% in the readings over those obtained when the bin was being filled or when the grain was at rest. The position of the diaphragm was then changed to one near the corner of the bin and the above procedure was repeated with practically the same readings as in the first test. During the removal of the grain the valve was suddenly closed several times, stopping the downward rush of the grain. This gave a slight increase of pressure, with a corresponding decrease when the valve was again opened.

The pressures obtained, both on the bottom and against the walls, were then plotted, the maximum readings of the different tests being used. The plottings and curves obtained are shown on the diagram marked A. fig. 7, page 41, and the pressures per square inch, both on the bin bottom and against its walls are given

in table I, page 42, which also shows the total side pressure, the relative vertical and lateral pressures and the coefficient of friction between grain and walls. The column of "equivalent fluid pressure" shows the pressure that would be produced by a fluid of the same specific gravity as the grain under the corresponding heads, or in other words, the pressures which would exist if there was no friction between the grain and the bin walls, and between the grains themselves.

Tests in Model Bins

In the following pages are given a description of the tests made by Mr. Jamieson in model bins, with the tables and curves which indicate the results obtained.

In support of these data, I must say that similar tests were made in Buenos Aires in full size bins, by Mr. Eckhardt Lufft, M. E.,* and the results agree very closely with those obtained by Mr. Jamieson in his model bins.

* Eng. News. Vol. 52, page 531

The experiments performed by Janssen* gave practically the same results, and they agree quite closely with those found theoretically by the same person. Therefore we see that the data given in the following pages is reliable and trustworthy.

* Full description of Janssen's tests are published in "Zeitschrift Des Verein Deutscher Ingenieure" 1895 Vol 39-page 1045

TESTS IN MODEL BINS.

The preceding described tests in the full-sized bins of the Canadian Pacific Elevator at St. John, N. B., gave all the data necessary to proceed with confidence with the designing of bins of approximately the same dimensions as the ones in which the tests were conducted. There still remained, however, considerable data to be obtained in order to devise a formula or system of calculating the pressures, and the proportion of grain weight that would be carried by the sides and on the bottom of bins of any ratio of breadth to depth or constructed of different materials.

After fully considering the question, the author believed that all the necessary data could be obtained by conducting a series of tests in model bins. This was undertaken in the winter of 1902-03, and the following testing apparatus was designed and manufactured:

One bin 12 ins. square, 6 ft. 6 ins. deep, the sides being made of corrugated or trough plate steel (corrugations running horizontally) attached to corner columns.

One bin 12 ins. square, 6 ft. 6 ins. deep, made of smooth wood boards.

One of the same dimensions as the last with the boards roughened on the inside of the bin, to imitate a bin of ordinary wooden cribbed construction.

One of the latter bins was also lined with flat steel plates to imitate a square steel bin.

One wooden bin 6 ins. square, 6 ft. 6 ins. deep.

One round steel bin 6 ins. diameter and 6 ft. 6 ins. deep.

One round steel bin 12 ins. diameter and 6 ft. 6 ins. deep.

Six hydraulic diaphragms: One being 12 ins. square, one 12 ins. in diameter, one 6 ins. square, one 6 ins. in diameter, one rectangular 3×12 ins., and one 2 ins. square.

In testing for bottom pressure the diaphragms were the full size of the different bins, forming a complete bottom for them. The total weight of grain coming on the bottom therefore rested directly upon a thin sheet of pure rubber, which in turn rested on the water contained in the diaphragm, while the bin itself rested upon the frame of the diaphragm. Connection was made between the diaphragm case and the glass gage column, which was set vertically alongside of a measuring scale. To obtain the lateral pressure the diaphragm was made to form part of the bin wall, the face being set vertical and in line with the inside face of the bin. (See diagram of arrangement of test bins, Fig. 2.)

The whole apparatus was set on a platform scale so that the weight of grain could be accurately taken as the bin was filled. The measuring scale was then adjusted accurately to the height of water in the gage glass. Grain was then poured into the top of the bin in drafts varying from 25 to 6¼ lbs. each, according to the size of bin used, and readings of the height of water column in the gages taken and recorded at each draft as the bin was filled.

Tests for bottom or vertical pressure were made in all the different bins, and for lateral pressure in a majority of the bins.

In the square trough-plate or corrugated-steel bins, tests were made with the following varieties of grain: Wheat, peas, corn or maize, and flax-seed; and in the cylindrical bins, tests were also made with thoroughly dry, clean river sand. The grain used was the highest grade that could be procured and was thoroughly clean and commercially dry; the wheat was No. 1 Manitoba Hard, weighing 50 lbs. per cu. ft., peas weighed 50 lbs., corn 45 lbs., and flax-seed 41.5 lbs. The sand weighed 100 lbs. per cu. ft. The weights as above were all carefully ascertained by means of the Grain Testers' Balance. Wheat was used to conduct the full series of tests, while the other grains were only tested in two of the bins, with a view to establishing the comparative pressures with wheat, over 50 separate tests being made in all. Some of the tests are given in full in the accompanying Tables IV. to VII., and the curves Figs. 5 to 8.

The tests were all carried out in duplicate. After the first series were completed, the readings plotted and calculations extended, the second series were undertaken with a view to checking the first, and to gain such additional information as was found to be desirable. In the first series the grain was poured into the bin from a pail, while in the second series of tests a funnel with a large opening was used. This did not make any difference in the maximum pressures obtained, but the latter mode of filling the bin gave very accurate curves when plotting the diagrams, while the plottings from the first series were in some instances somewhat erratic.

TESTS UNDER SPECIAL CONDITIONS.

With a view to ascertaining the effect of vibrations or shocks on the pressures, the sides of the bin were sharply tapped with a hammer. It was found that by tapping the bin near the bottom only, the pressure or load on the bottom could be decreased. This was found to be due to a slight deflection in the bin sides, which, however, was not sufficient to allow the grain in the upper part of the bin to settle down. When, however, the tapping was continued from the bottom to the top of the bin on all sides,

the grain in the bin could be settled from 2 to 3 ins., giving a slightly increased pressure on the bottom. In test No. 1A, the full records of which are given in Table IV., it will be noted that the settling of the grain amounted to 2¼ ins., giving a maximum reading of 10½ ins. of water, or an increase due to the shock of 1¼ ins. of water, equal to total increased weight on bottom of approximately 9 lbs. It may be stated that this shock was proportionately very much greater than could be produced under ordinary conditions in large elevator bins.

The author may state here that while vibration or shock will slightly increase both the vertical and lateral pressure, as the lateral pressure increases the total friction on the wall will correspondingly increase and therefore there cannot be found any good reason for assuming any material increase of pressure due to shocks. Again, by slightly raising the bin with screws inserted between the frame of the diaphragm and the bottom of the bin walls, the pressure on the bottom could be very materially decreased. This decrease, allowing the water in the gage to recede from the maximum of 10½ ins. to 7 ins., clearly shows that the greater the pressure on the sides the greater the load carried by the walls.

On the bin being again lowered to its original position, while no increase of lateral pressure was shown by the side diaphragm, there was a very large increase of pressure on the bottom diaphragm, or sufficient to cause the water to flow out of the top of the 4-ft. gage glass tube, which was not therefore long enough to record the pressure; in fact, the total weight of the grain was then resting on the bottom diaphragm, and in addition the grain was acting as a column to support the weight of the bin itself.

Again, by placing standard weights of 50 lbs. each on top of the grain, the pressure on the bottom could be only slightly increased by each weight applied, and it decreased again as the weights were removed. This experiment was repeated a number of times, in one case 400 lbs. of weights being applied, with practically the same results in every case; indicating clearly that the increased pressure on the bottom by the application of weights on the top of the grain, was due to a slight vertical compression of the bin walls, or the elasticity of the grain.

Very careful tests were also made to ascertain the pressure due to grain in motion, or when the grain was being drawn out of the bin. To obtain the bottom pressure, the grain was drawn from an opening in the side of the bin close to the bottom. There was found to be a decrease of pressure on the bottom when the gate was opened and this decrease was maintained until the bin was about half emptied, then it became approximately the same as when the bin was being filled. Near the bottom the pressures showed an increase over the curve obtained when filling the bin; this, however, was entirely due to the necessity of drawing the grain from the one side of the bin, as when nearly emptied, the remaining grain was all on one side of the bin and therefore nearly all resting on the bottom.

When the grain was being drawn from the opening at the side of the bin, it was found that there was considerable difference in lateral pressure on the different sides. On the side directly opposite to the opening there was a large increase of pressure, and on the same side as the opening the pressure decreased to less than half when the 3-in. $\times$ 12-in. rectangular diaphragm was being used; and when the 2-in. square diaphragm was placed directly over and a short distance above the opening, there proved to be practically no lateral pressure at this point. (See Fig. 8.)

When the bin is being filled or when the grain is being drawn from the opening of a square or cylindrical bin through an opening exactly in the center, a line drawn vertically through the center of the bin is the center of pressure, and the lateral pressure per square inch is equal on all sides of the bin. If, however, the grain should be drawn from an opening in the side of the bin, or in the bottom close to the side, then, owing to the moving col-

umn of grain being over the opening, the center of pressure is changed, and the lateral pressure is considerably increased on the side opposite to the opening and decreased on the side over the opening, thus throwing very uneven strains into the bin walls. In a square bin, this will simply throw the increased pressure on the far wall, but in a cylindrical bin this must have a very injurious effect, unless the walls should be of very rigid construction. In a steel tank, the walls of which are very thin and have practically no rigidity, this uneven pressure tends to throw the tank considerably out of round, while the decreased pressure on the side over the opening makes this part of the tank shell very unstable as a column to carry the vertical load, with the result that steel tanks often buckle inward at varying distances above the opening. This conclusively shows that in all bins, and especially in those of cylindrical shape, to avoid these excessive strains the grain should always be drawn from an opening in the center of the bin.

To properly ascertain the lateral pressure when the grain was being drawn from an opening in the center (which is the usual manner in small bins) the bin was provided with a hopper bottom, with the gate opening directly in the center, the diaphragm being placed on the side as before. The grain was then drawn out and weighed, the gage carefully observed, readings recorded at the end of each draft, or when the gate was closed, and to ensure getting all fluctuations of pressure, two or three intermediate readings were taken while the grain was in motion. Several similar tests were made with varying sizes of gate openings and grain running out at speeds varying from 50 lbs. to 120 lbs. per minute, and the increase of lateral pressure due to grain in motion over grain at rest, or when the bin was being filled, was found to vary from 5% to 9.3%, the latter being for the highest speed, which is, however, relatively much greater than would be attained in practice in full-sized bins.

Tests were also made by pouring grain in at the top at varying speeds, while it was being drawn out at the bottom, but this was found to have no appreciable effect until the bin was nearly emptied, and the pressure had considerably decreased. By pouring grain in at a higher speed than it was being drawn out, the pressure could be again raised, but in no case beyond the maximum of 9.3% over that obtained while filling the bin.

If the grain is drawn from the center of the bin, it may be safely stated that the increase of pressure due to the grain in motion, over grain at rest, or when the bin is being filled, will not exceed 10% and the increase will be considerably less than this when the ratio of the area of the gate opening to the area of the bin is 1 to 150, which is approximately the usual practice in standard-sized bins.

That no large increase of pressure actually takes place due to grain in motion, when the grain is being drawn

from the center of the bin bottom is, I believe, fully demonstrated by the above tests, and also by the tests in the full-sized bins at St. John, N. B. In addition, the author has on three different occasions made careful measurements of the deflection of the walls of different elevator bins, 1, when they were being filled; 2, after the grain had been at rest for several days, and, 3, when the grain was being drawn out. One of the records is as follows:

Bin filled with wheat. Cribbed spruce walls. Thickness of wall, 6 $\frac{3}{4}$ ins. Clear span 13 ft. 5 $\frac{1}{4}$ ins. Depth of grain in prism of bin, 65 ft. Height of grain above point of measurement for deflection, 60 ft. Deflection when first loaded, $\frac{5}{8}$ -in. Deflection when four days under load, 11-16-in. When grain was being drawn out, the deflection varied from $\frac{3}{8}$ -in. to a maximum of slightly under $\frac{1}{2}$ -in., the latter deflection being when the gate was suddenly closed.

Careful calculations were made for the fiber stress in the walls, and it was found that this deflection would be approximately equal to a distributed load of 352 lbs. per square foot of wall.

Tests were also conducted with a view to ascertaining the complete movement of the grain when it was being drawn out and to find relative speed of the downward movement of the grain at different points in the bin. To facilitate this, the bin was provided with a glass side, and different colored grains placed at equal distances apart vertically. The gate was then opened and the movement of the grain down the glass side observed and the time taken when each of the colored grains came out of the bottom. It was found that a column of grain directly over the opening in the center of the bin moved at the highest rate of speed, the vertical movement decreasing towards

the sides, the whole column of the grain in the bin, however, moving downward. There was a small triangular section of grain at the bottom of the bin, which did not move out until the last. Thus, a part of the first grain put in the bin was the last to run out. (See sketch B, Fig. 2.)

Tests were also made by placing small $\frac{1}{2}$ -in. by 24-gage steel bars across the center of the bin in both directions, spaced 6 ins. apart vertically, the bars being set on edge with a view to presenting the least resistance to the moving grain column. (See sketch C, Fig. 2.) It was found that the bars had a very decided effect on the vertical movement of the grain; in fact, $\frac{1}{3}$ less grain would run through the opening at the bottom in a given time, as in the same bin with the same opening, without tie bars. This shows that when the grain is moving down a very heavy strain must be thrown into the tie bars, and through the tie bars into the walls; that the vertical grain load carried by the walls will be considerably increased; and that tie bars, if used at all, should not run across the center of a bin. All tie bars or other obstructions, however, in a bin will be subjected to considerable strain and should be avoided if at all possible.

All the above tests were made in bins 12 ins. square and 12 ins. diameter by 6 ft. 6 ins. deep, and it was found that with the walls giving the same coefficient of friction and having the same ratio of wall area to horizontal area of the bin, there was practically no difference in pressure between the square and cylindrical bins. The pressure varied, however, directly as the coefficient of friction, taking as an example:

Test No. 1A, Table IV., Bin 12 ins. square, horizontally corrugated steel sides; wheat in bin, 325 lbs.; weight on bottom, 45.46 lbs.; coefficient of friction, 0.468.

Test No. 5A, Table V., Bin 12 ins. square, flat steel plate sides; wheat in bin, 325 lbs.; weight on bottom, 60.397 lbs.; coefficient of friction, 0.355.

The latter gave vertical and lateral pressures 32.9% greater than the former, and the walls of the former bin carried 4.88% more of the total weight of the grain in the bin than the latter.

A test was made by using a stout canvas bag or cylinder 12 ins. in diameter, 6 ft. 6 ins. deep, provided with metal rings at both ends, one ring attached to the metal frame of the 12-in. circular diaphragm. It will be noted that this formed a cylindrical bin with wall incapable of supporting any vertical load. The bag was extended to full height and the wheat poured in at the top. When the bag was full, it was found that the height of water in the gage glass multiplied by the area of the diaphragm gave 1 $\frac{1}{2}$ lbs. more than the total weight of grain, showing that the grain column was supporting a part of the weight of the bag, which weighed 3 $\frac{1}{4}$ lbs., and incidentally proving the correctness of the hydraulic diaphragm and water column as an accurate weighing machine.

A test was also made in the 12-in. diameter cylindrical bin, using sand instead of grain. The sand was thoroughly dry, clean and of good building quality; angle of repose, 34°; weight, 100 lbs. per cu. ft. When 537 $\frac{1}{2}$ lbs. were put into the bin, it was found that 99.211 lbs. or 18.45% was resting on the bottom and 438.289 lbs. or 81.55% carried by the sides. (It is interesting to note that both sand and wheat gave approximately the same percentage of total weight resting on the bin bottom or diaphragm. The wheat weighed 50 lbs. per cubic foot and gave 18.29% on the bottom and 81.71% carried on the sides.) By sharply tapping the cylinder on both sides with the hands, we settled the sand 3 inches, increasing the load on the bottom to 120.272 lbs. or 22.37% of the total weight of sand in the bin.

In conducting the tests, the coefficient of friction between the grain and the bin walls was readily obtained in the following manner: Having found the total grain weight resting on the bottom of the bin, we deduct this bottom weight from the total weight of the grain in the bin. This gives the weight supported by the walls, and by dividing this weight into the total side pressure, we get the coefficient of friction. The total side pressure was obtained by multiplying the pressure per square inch for each section of the bin, by the area of the walls for that section, and the sum of the pressures per section give the total pressure on the bin walls. The coefficient of friction obtained in the above manner agreed very closely in every case with the coefficients obtained by means of the apparatus shown in Fig. 3.

To obtain the relative pressures due to increased breadth or diameter of bin, tests were made in the bins 6 ins. square and 6 ins. diameter, by 6 ft. 6 ins. deep. It was found in each case that the pressures per square inch,

a comparatively easy problem in simple arithmetic to determine the vertical and lateral pressures and the proportion of the weight of the contents of a bin of any given breadth and depth, or of any construction of walls, that will be carried by the walls and on the bin bottom. For the purpose of illustrating this method, we will assume a bin 10 ft. square, 100 sq. ft. horizontal area, filled with wheat weighing 50 lbs. per cu. ft.; each layer one foot thick will contain 100 cu. ft. weighing 5,000 lbs. and the area of the four walls for one foot in depth of bin, will be 40 sq. ft.

Starting with the top layer, we find that the lateral pressure, and therefore the friction between the grain and the walls, is very slight and may be neglected, and assume that the full weight of the first layer is resting on top of the second layer. We therefore have:

$$\frac{5,000 \times 40}{100} \times 0.6 \times 0.41667 = 500 \text{ lbs.}$$

carried by the walls.

This 500 lbs. deducted from the weight of the second layer will leave 4,500 lbs. (which we will call the remaining weight) plus the full weight of the first layer, making 9,500 lbs. which will rest on top of the third layer, and will produce lateral pressure in the third layer sufficient to support 950 lbs.; deducted from the weight of the third layer this will give a remaining weight of 4,050 lbs. Adding this to the remaining weight of the second layer, and the full weight of the first layer, will give the pressure on top of the fourth layer, and so on for all succeeding layers. As the weight on top of each layer increases, the lateral pressure will be correspondingly increased, and the greater the pressure against the walls, the greater proportion of each layer that will be supported by the walls. While the weight being added to the bottom pressure by each succeeding layer, will correspondingly decrease, until a depth has been reached where the pressure against the sides becomes sufficient to cause the full weight of the layer to be supported, by the walls, then the maximum lateral pressure has been reached, and no further weight will be added to the bottom. The total weight on the bottom of a bin will therefore be equal to the sum of the weight of the top layer plus the remaining weights of all succeeding layers, and the weight carried by friction on the bin walls will be the difference between the weight on the bottom and the weight of the total amount of grain in the prism of the bin.

This may be called the "step process," and calculations may be made in this manner to obtain the pressures in any given size or construction of bin filled with grain or any other strictly granular material.

Table III., on p. 239, gives the pressures for bins 10 ft. and 20 ft. square and 80 ft. deep, was calculated by the above process. The two columns at right of the tables give the pressures calculated by "Pressure Factors" obtained by the tests.

While this process is very simple, it is a somewhat long and tedious one, by which to make the calculations for deep bins; but is undoubtedly correct and agrees in every particular with the results obtained from the author's tests, both in the model and full-sized bins, and also with Janssens' tests, mentioned earlier in this paper. This process may, however, be reduced to a very simple formula since we find that no matter how deep the bin may be, if the walls be not compressed vertically due to the load, we can readily find the maximum vertical and lateral pressure in a bin of any given dimensions, filled with any granular material.

Assuming as above, a bin 10 ft. square, filled with wheat weighing 50 lbs. per cu. ft., the coefficient of friction between grain and the bin walls as 0.41667 and the angle of repose of the grain as 28° and therefore the ratio of bottom to side pressure as 1:0.65. We have the total side pressure required in a layer 1 ft. deep to support the total weight of that layer by friction on the wall, as follows:

$$L = \frac{5,000}{0.41667} = 12,000 \text{ lbs. pressure to support 5,000}$$

lbs., and the side pressure per sq. ft.

$$1 = \frac{5,000}{0.41667 \times 40} = 300 \text{ lbs., or 2.08 lbs. per sq. in.}$$

The bottom pressure per sq. ft. will therefore be

$$V = \frac{5,000}{0.41667 \times 40 \times 0.6} = 500 \text{ lbs., or 3.47 lbs. per sq. in. and the total bottom pressure will be}$$

$$\frac{5,000 \times 100}{0.41667 \times 40 \times 0.6} = 50,000 \text{ lbs. on horizontal}$$

bottom.

It happens that this 50,000 lbs. total weight on the horizontal bottom of the bin is exactly equal to the weight of a column of grain having a height equal to the horizontal dimensions of the bin, and this would hold true for any square or cylindrical bin having the same coefficient of friction, filled with material having the same weight and angle of repose. If, however, the coefficient of friction should be lower, the weight on the bottom will be correspondingly higher, or vice versa. If the angle of repose should be lower and the coefficient of friction between the grain and the bin walls remain the same, then the lateral pressure would be greater, and the weight on the bottom lower, but since a lower angle of repose of the grain will usually give a lower coefficient of friction, between the grain and the bin walls, the angle of repose of the grain will always have considerable bearing on the latter, in addition governing the relative vertical and lateral pressure.

We will therefore assume a bin of the same size as before, filled with grain weighing 50 lbs. per cu. ft. with the coefficient of friction as 0.35, angle of repose of grain 24° and therefore a ratio of bottom to side pressure of 1:0.65. We have the side pressure per sq. ft.:

$$1 = \frac{5,000}{0.35 \times 40} = 357 \text{ lbs., or 2.48 lbs. per sq. in.}$$

Bottom pressure per sq. ft.

$$V = \frac{5,000}{0.35 \times 40 \times 0.65} = 549 \text{ lbs., or 3.82 lbs. per sq. in.}$$

and the total bottom pressure

$$\frac{5,000 \times 100}{0.35 \times 40 \times 0.65} = 54,946 \text{ lbs. on horizontal bottom.}$$

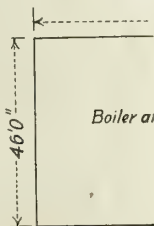
It must be borne in mind that the preceding formula gives only the maximum vertical and lateral pressures and grain load on the horizontal bottom of the bins when the bins are being filled, or the grain at rest. No matter how deep the bin may be, if the bin walls be not compressed vertically due to the load these maxima will not be materially exceeded.

In a bin having a hopper bottom, the weight of grain in hopper must be added to the total weight on horizontal bottom.

The pressures obtained by the foregoing system of calculation agree accurately with the tests made in the model bins, and the pressures obtained in the latter, multiplied by the increased breadth or diameter agree most closely with the tests made in the full-sized grain bins of the same ratio of breadth to depth.

The author believes that he has fully demonstrated that the pressure produced by grain stored in deep bins is only a small percentage of the pressure that would be produced by fluids of the same specific gravity, and that the pressures produced by grain or any other dry granular material stored in bins of any dimensions may be accurately calculated.

Wheat and corn are the two varieties of grain which are most largely stored and handled. Taking wheat weighing 50 lbs. per cu. ft., as a standard, we find that corn weighing 45 lbs. per cu. ft., will give approximately the same pressure per square inch as wheat; this being due to the slightly lower coefficient of friction between the corn and the bin walls. Peas, weighing 50 lbs. per cu. ft. give a vertical and lateral pressure of approximately 20% greater than wheat; while flax-seed, weighing 45 lbs. per cu. ft. will give a lateral pressure 10% greater, and a vertical pressure 12% greater than wheat, this being due to its lower angle of repose, and lower coefficient of friction. A bin designed with a proper factor of safety for wheat will, however, be quite safe for the storage of peas or flaxseed.



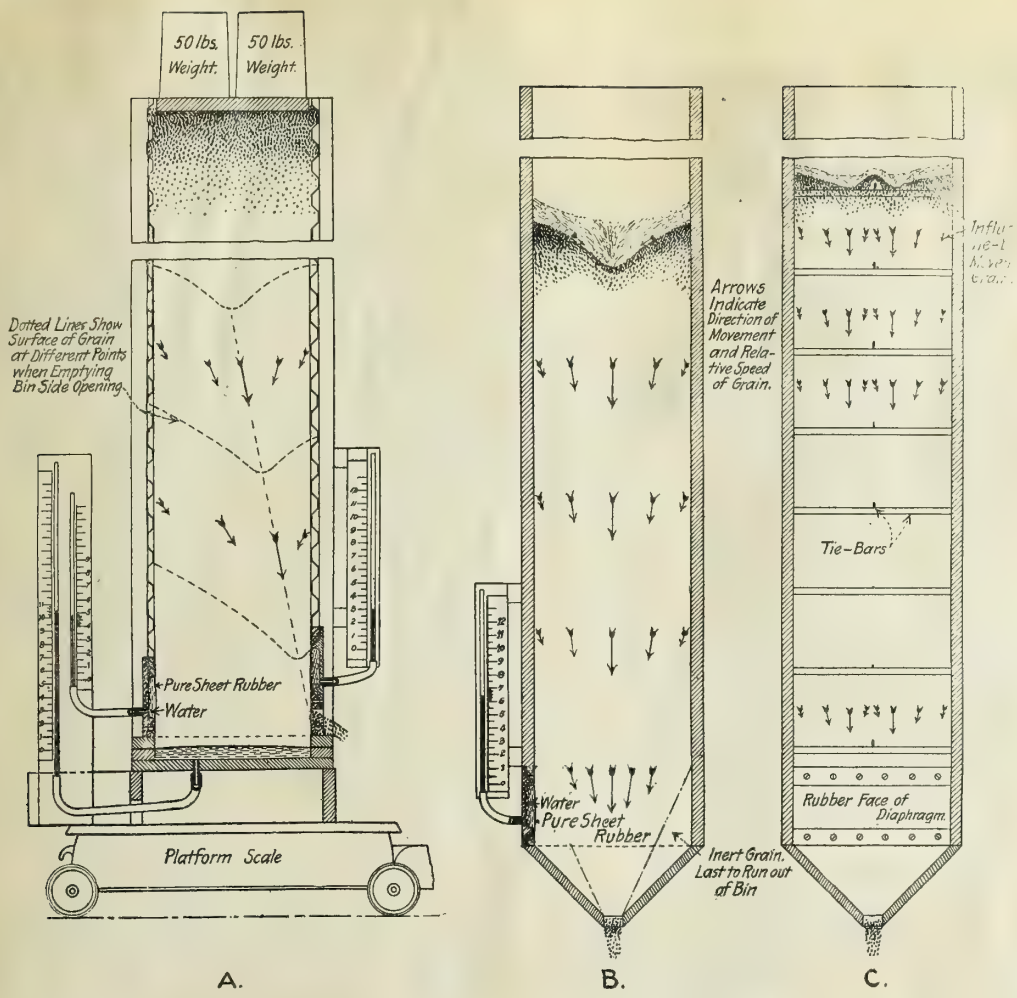


FIG. 2. ARRANGEMENT OF APPARATUS IN MODEL-BIN TESTS.

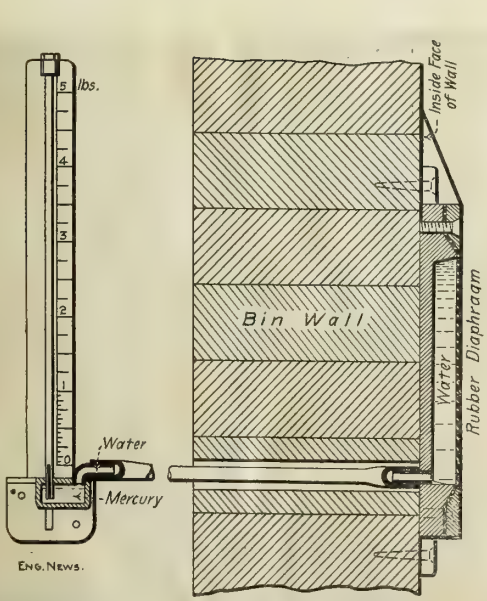


Fig. 1. Hydraulic Diaphragm Used for Grain-Pressure Tests in Full-Size Bins.

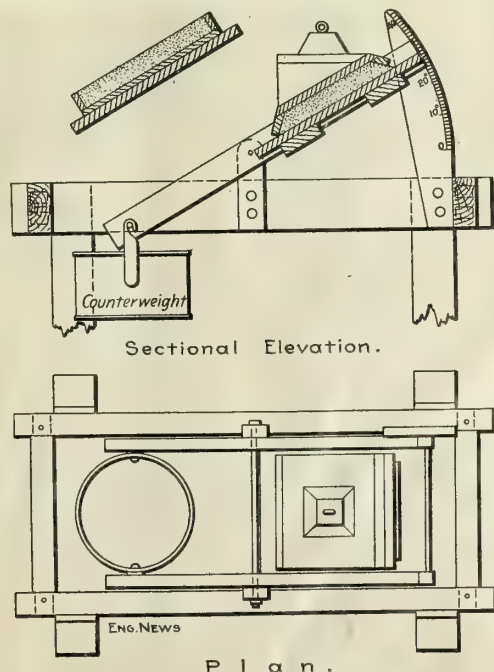


Fig. 3. Apparatus for Obtaining Angle of Repose and Coefficient of Friction of Grain Against Bin Wall.

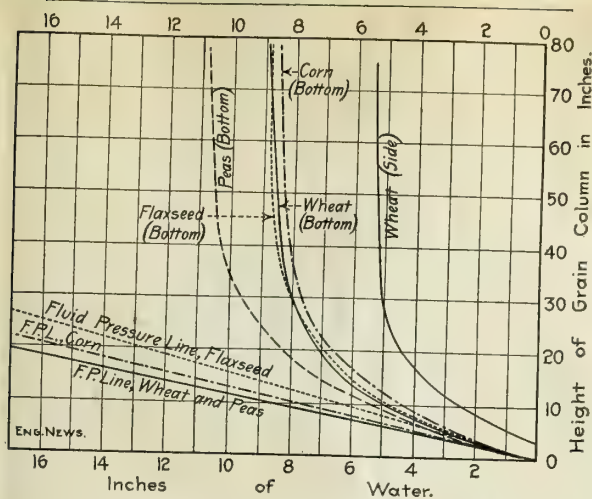


Fig. 5. Pressure Curves for Various Materials in Model Bin.

(Bin 12 ins. square by 6 ft. 6 ins. high. Bin sides made of trough-plate.)

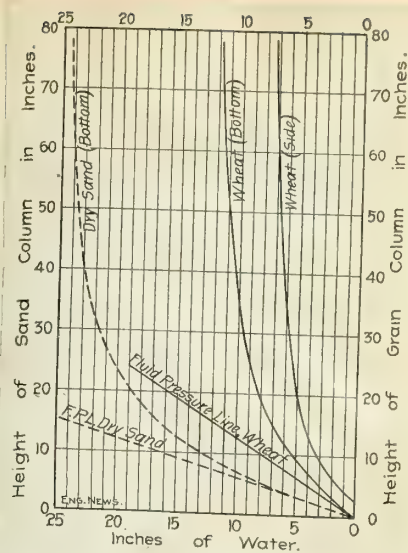


Fig. 6. Comparative Pressures of Wheat and Dry Sand.

Circular steel bin, 12 ins. diam. by 6 ft. 6 ins. deep.
Wheat, 50 lbs. per cu. ft.
Sand, 100 lbs. per cu. ft.

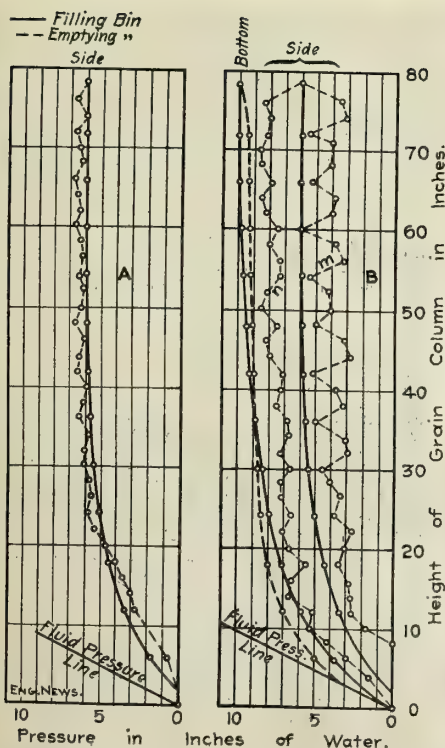


Fig. 8. Curves Showing Variations in Grain Pressure Due to Filling and Emptying Bins, with Outlet Opening at Center or at Side of Bottom; Model-Bin Tests.

A—Curve of side pressures, outlet opening in center of bottom.

B—Curves of side and bottom pressures, outlet opening at side of bottom.

Note.—Side pressure is shown both for side adjacent to outlet (curve m), and for side opposite outlet (curve n).

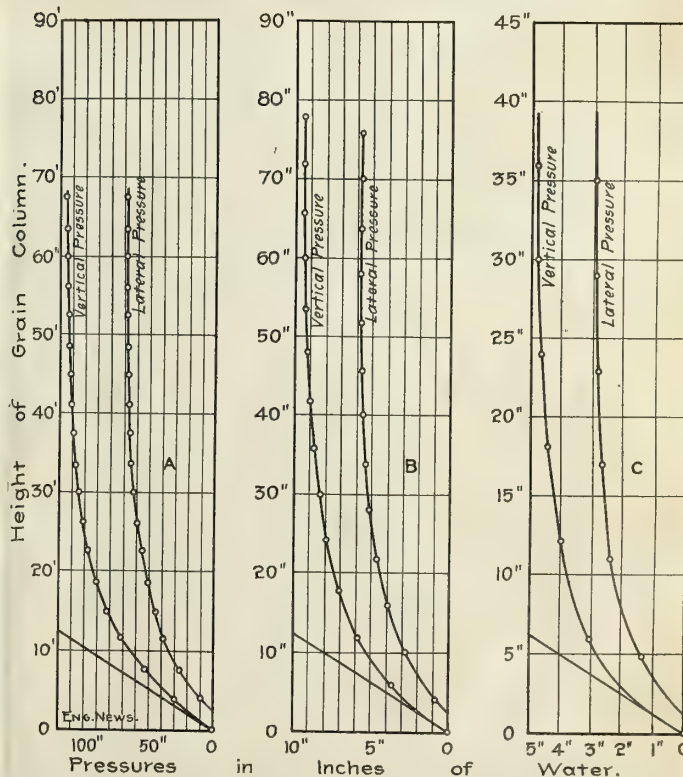


Fig. 7. Comparative Curves of Pressures in Full-Size and Model Bins.

A.—St. John Tests on Full-Size Bin.
Wheat in wooden bin, 12 ft. x 13 ft. 6 ins. by 67 ft. 6 ins. deep.

B.—Model Bin Tests.
Wheat in cribbed wooden bin, 12 ins. square by 6 ft. 6 ins. high.

C.—Model Bin Tests.
Wheat in wooden bin, 6 ins. square by 3 ft. 3 ins. high.

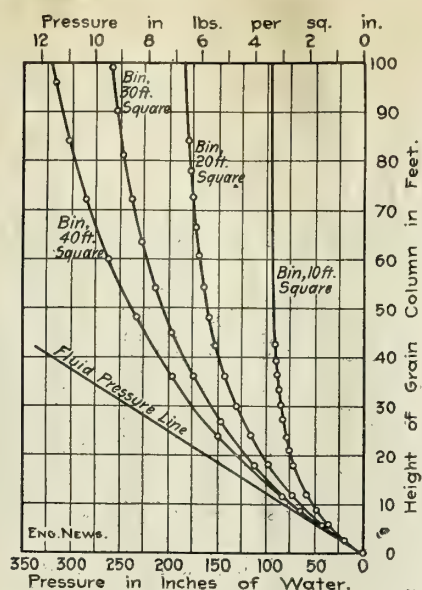


Fig. 9. Computed Curves of Pressure for Wheat in Bins of Various Sizes.

Weight of wheat, 50 lbs. per cu. ft.
Angle of repose, 28°.
Coefficient of Friction bet. grain and bin-side, 0.417.

TABLE I.—Grain Pressure Tests in Full-Size Bin.

Tests made with wheat in cribbed wooden bin, Canadian Pacific Ry., elevator at West St. John, N.B., Canada. Inside dimensions of bin, 12 ft. x 13 ft. 6 ins. = 23,328 sq. ins. Depth of bin, 67 ft. 6 ins. Wheat used for test, No. 1 Hard Manitoba, weighing 49.4 lbs. per cu. ft.. Weighed into bin in drafts of 30,000 lbs., giving each 3 ft. 9 ins. depth of grain in bin.

Grain in prism of bin.....		540,000 lbs.							
Grain in hopper bottom		16,500 "							
Total grain in bin		556,500 lbs.							
Grain weighed into bin, in lbs.	Height of grain column, in ft. ins.	Equivalent fluid pressure, in lbs. per sq. in.	Pressure of grain		Total; side, per section, in lbs.	Grain carried			
			Vertical; on bottom, in lbs. per sq. in.	Side; at bottom of walls in lbs. per sq. in.		On bottom		On sides	
						Weight, lbs.	Total weight, %.	Weight, lbs.	Total weight, %.
30,000	3 9	1.286	1.118	0.343	9,446	26,081	86.9	3,919	13.1
60,000	7 6	2.573	1.948	0.938	25,832	45,443	75.7	14,557	24.3
90,000	11 3	3.859	2.499	1.317	36,270	58,297	64.7	31,704	35.3
120,000	15 0	5.145	2.927	1.615	44,477	68,291	56.9	51,719	43.1
150,000	18 9	6.431	3.247	1.804	48,682	75,746	50.4	74,254	49.6
180,000	22 6	7.718	3.482	2.011	53,382	81,228	45.1	98,772	54.9
210,000	26 3	9.004	3.635	2.111	58,136	84,797	40.3	125,203	59.7
240,000	30 0	10.290	3.752	2.201	60,615	87,527	36.4	152,473	63.6
270,000	33 9	11.576	3.843	2.278	62,786	89,650	33.2	180,350	66.8
300,000	37 6	12.863	3.924	2.345	63,581	91,539	30.5	208,461	69.5
330,000	41 3	14.149	3.987	2.381	65,672	93,009	28.1	236,991	71.9
360,000	45 0	15.435	4.041	2.417	66,564	94,268	26.1	265,732	73.9
390,000	48 9	16.721	4.077	2.435	67,059	95,108	24.3	294,892	75.7
420,000	52 6	18.008	4.095	2.453	67,555	95,528	22.7	324,472	77.3
450,000	56 3	19.294	4.113	2.453	67,555	95,948	21.3	354,052	78.7
480,000	60 0	20.580	4.129	2.453	67,555	96,321	20.1	383,679	79.9
510,000	63 9	21.866	4.129	2.462	67,803	96,321	18.8	413,679	81.2
540,000	67 6	23.153	4.129	2.462	67,803	96,321	17.8	443,679	82.2

Note 1.—When bin is full the distribution of loads is as follows:

Vertical pressure	96,321 lbs.
Grain in hopper	16,500 "
Total load on hopper bottom	112,821 lbs.
Total vertical load carried by bin walls	443,679 lbs.
Total grain in bin	556,500 lbs.

Note 2.—Relative Vertical and Lateral Pressure.—Total pressure on bottom due to 67 ft. 6 ins. grain = 4.129 lbs. per sq. in. multiplied by area of bottom, 23,328 sq. ins. = 96,321 lbs. Maximum pressure on side of bin due to 67 ft. 6 ins. grain = 2.462 lbs. per sq. in. Lateral pressure = 59.6% of vertical pressure, or vertical pressure = 1.66 lateral pressure. Coefficient of friction between grain and sides of bin

$$\frac{\text{Weight carried by sides}}{\text{Total side pressure}} = \frac{443,679}{1,004,632} = .441.$$

TABLE III.—COMPUTED PRESSURES OF WHEAT, IN BINS 10 x 10 FT. AND 20 x 20 FT., 80 FT. DEEP.

Lateral pressure = 0.6 x vertical pressure. Weight of wheat, 50 lbs. per cu. ft. Angle of repose, 28°; 1 = 0.6 V. Coefficient of friction between grain and bin walls = 0.41667.

10 x 10 ft. bin.										20 x 20 ft. bin.									
Height of grain.	Weight in bin, lbs.	Carried by			Pressure per sq. in., lbs.			By pressure			Carried by			Pressure per sq. in., lbs.			By pressure		
		Sides		Per ft., lbs.	Total, lbs.	Bottom, lbs.	Height of grain, in bin, lbs.	Per ft., lbs.	Total, lbs.	Bottom, lbs.	Sides	Per ft., lbs.	Total, lbs.	Bottom, lbs.	Height of grain, in bin, lbs.	Per ft., lbs.	Total, lbs.	Bottom, lbs.	Sides
		Per ft., lbs.	Total, lbs.								Per ft., lbs.	Total, lbs.							
1 ft.	5,000	0.00	0.00	5,000	5,000	1.28	2.28	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00
2 "	10,000	0.00	0.00	10,000	10,000	1.61	2.78	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
3 "	15,000	0.00	0.00	15,000	15,000	1.80	3.07	0.00	0.95	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00
4 "	20,000	0.00	0.00	20,000	20,000	1.99	3.35	0.00	1.23	0.00	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00
5 "	25,000	0.00	0.00	25,000	25,000	2.03	3.41	0.00	1.51	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
6 "	30,000	0.00	0.00	30,000	30,000	2.05	3.45	0.00	1.79	0.00	0.00	0.00	0.00	0.00	1.78	0.00	0.00	0.00	0.00
7 "	35,000	0.00	0.00	35,000	35,000	2.06	3.47	0.00	2.07	0.00	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00	0.00
8 "	40,000	0.00	0.00	40,000	40,000	2.07	3.48	0.00	2.35	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00	0.00
9 "	45,000	0.00	0.00	45,000	45,000	2.07	3.48	0.00	2.63	0.00	0.00	0.00	0.00	0.00	2.62	0.00	0.00	0.00	0.00
10 "	50,000	0.00	0.00	50,000	50,000	2.08	3.49	0.00	2.91	0.00	0.00	0.00	0.00	0.00	2.90	0.00	0.00	0.00	0.00
15 "	75,000	0.00	0.00	75,000	75,000	2.08	3.49	0.00	3.19	0.00	0.00	0.00	0.00	0.00	3.18	0.00	0.00	0.00	0.00
20 "	100,000	0.00	0.00	100,000	100,000	2.08	3.49	0.00	3.47	0.00	0.00	0.00	0.00	0.00	3.46	0.00	0.00	0.00	0.00
25 "	125,000	0.00	0.00	125,000	125,000	2.08	3.49	0.00	3.75	0.00	0.00	0.00	0.00	0.00	3.74	0.00	0.00	0.00	0.00
30 "	150,000	0.00	0.00	150,000	150,000	2.08	3.49	0.00	4.03	0.00	0.00	0.00	0.00	0.00	4.02	0.00	0.00	0.00	0.00
35 "	175,000	0.00	0.00	175,000	175,000	2.08	3.49	0.00	4.31	0.00	0.00	0.00	0.00	0.00	4.30	0.00	0.00	0.00	0.00
40 "	200,000	0.00	0.00	200,000	200,000	2.08	3.49	0.00	4.59	0.00	0.00	0.00	0.00	0.00	4.58	0.00	0.00	0.00	0.00
45 "	225,000	0.00	0.00	225,000	225,000	2.08	3.49	0.00	4.87	0.00	0.00	0.00	0.00	0.00	4.86	0.00	0.00	0.00	0.00
50 "	250,000	0.00	0.00	250,000	250,000	2.08	3.49	0.00	5.15	0.00	0.00	0.00	0.00	0.00	5.14	0.00	0.00	0.00	0.00
55 "	275,000	0.00	0.00	275,000	275,000	2.08	3.49	0.00	5.43	0.00	0.00	0.00	0.00	0.00	5.42	0.00	0.00	0.00	0.00
60 "	300,000	0.00	0.00	300,000	300,000	2.08	3.49	0.00	5.71	0.00	0.00	0.00	0.00	0.00	5.70	0.00	0.00	0.00	0.00
65 "	325,000	0.00	0.00	325,000	325,000	2.08	3.49	0.00	5.99	0.00	0.00	0.00	0.00	0.00	5.98	0.00	0.00	0.00	0.00
70 "	350,000	0.00	0.00	350,000	350,000	2.08	3.49	0.00	6.27	0.00	0.00	0.00	0.00	0.00	6.26	0.00	0.00	0.00	0.00
75 "	375,000	0.00	0.00	375,000	375,000	2.08	3.49	0.00	6.55	0.00	0.00	0.00	0.00	0.00	6.54	0.00	0.00	0.00	0.00
80 "	400,000	0.00	0.00	400,000	400,000	2.08	3.49	0.00	6.83	0.00	0.00	0.00	0.00	0.00	6.82	0.00	0.00	0.00	0.00
Maximum		5,000	50,000	0	50,000	2.08	3.50	2.08	3.50	2.08	5,000	50,000	0	50,000	2.08	3.50	2.08	3.50	2.08

TABLES OF TESTS ON GRAIN PRESSURE IN MODEL BINS.

MADE BY J. A. JAMIESON, MONTREAL, P. Q., 1903.

TABLE IV.—WHEAT IN TROUGH-PLATE BIN, 12×12 INS. BY 6 FT. 6 INS. HIGH.

Weight of grain, 50 lbs. per cu. ft. = 62.2 lbs. per bushel. Each section of grain weighed in = 6 ins. high, weighing 25 lbs., and having a wall area of 288 sq. ins.
 BOTTOM PRESSURE TEST. SIDE PRESSURE TEST.
 12×12-in. diaphragm horizontally on bottom; 6×6-in. diaphragm vertically in side of bin;
 = 144 sq. ins. area. = 36 sq. ins. area.

Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.	Grain carried on bottom.		Grain carried on bin-side.		Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.		Side pressure per section.	Grain running out pressure of grain on diaphragm.	
				Weight.	% of total weight of grain.	Weight.	% of total weight of grain.				ins.	lbs. per sq. inch		ins.	lbs. per sq. inch
lbs.	in.	in. water.	in. water	lbs.		lbs.		lbs.	ins.	ins. water	ins.	lbs. per sq. inch	lbs.	ins. water	lbs. per sq. inch
25	6	4.81	3½	18.184	72.7	6.816	27.3	25	6	4.81	0.02255	6.494	1½	0.054120	
50	12	9.62	5½	28.575	57.1	21.425	42.9	50	12	9.62	0.09020	25.978	3½	0.135300	
75	18	14.43	6¾	34.420	45.9	40.580	54.1	75	18	14.43	0.13981	40.265	5	0.180400	
100	24	19.24	7¾	38.966	38.9	61.034	61.1	100	24	19.24	0.16461	47.409	5	0.180400	
125	30	24.05	7¾	40.914	32.7	84.086	67.3	125	30	24.05	0.17138	49.357	5½	0.189420	
150	36	28.86	8½	41.888	27.8	108.112	72.2	150	36	28.86	0.17589	50.656	5½	0.189420	
175	42	33.67	8½	42.863	24.5	132.137	75.5	175	42	33.67	0.18040	51.955	5½	0.189420	
200	48	38.48	8½	43.837	21.9	156.163	78.1	200	48	38.48	0.18491	53.254	5½	0.189420	
225	54	43.29	8½	44.161	19.6	181.839	80.4	225	54	43.29	0.18491	53.254	5½	0.189420	
250	60	48.10	8½	44.161	17.6	205.839	82.4	250	60	48.10	0.18716	53.903	5½	0.193930	
275	66	52.81	8½	44.486	16.1	230.514	83.9	275	66	52.81	0.18942	54.553	5½	0.198440	
300	72	57.62	8½	45.460	15.1	254.540	84.9	300	72	57.62	0.18942	54.553	5½	0.198440	
325	78	62.53	8½	45.460	13.9	279.540	86.1	325	78	62.53	0.18942	54.553	5½	0.200695	

Effect of 50lbs. of weights placed on top of grain column :—

682	163.68	131.27	9½	48.708	7.1	633.292	92.9
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Increase of pressure on bottom by placing weights on top of grain column in bin :—

Weights.	Increases gauge reading		Increases in	
	From	To	Inches	lbs
lbs.				
50	8½	9½	1	3,247
100	9½	10	1	3,247
150	10	10½	1	3,247
	Total increase		1½	9,741

When weights were removed gauge returned to 8½"

NOTE.—By sharply tapping sides of bin, grain settled 2¼" from top, and gave a maximum gauge reading of 10½ in. of water, equal to a load on bottom of 54.553lbs., or 16.78 % of total weight of grain in bin.

By raising bin by means of screws at the corners, the gauge receded to 7 inches.

TABLE V.—WHEAT IN SHEET-STEEL BIN 12×12 INS. BY 6 FT. 6 INS. HIGH.

Weight of grain, 50 lbs. per cu. ft. = 62.2 lbs. per bushel. Each section of grain weighed in = 6 ins. high, weighing 25 lbs., and having a wall area of 288 sq. ins. Bottom and side pressure-tests made simultaneously.
 BOTTOM PRESSURE TEST. SIDE PRESSURE TEST.
 12×12-in. diaphragm horizontally on bottom; 6×6-in. diaphragm vertically in side of bin;
 = 144 sq. ins. area. = 36 sq. ins. area.

Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.	Grain carried on bottom.		Grain carried on bin sides.		Grain weighed into bin.	Height of grain column.	Equivalent fluid pressure.	Pressure of grain on diaphragm.		Side pressure per section.
				Weight.	% of total weight of grain.	Weight.	% of total weight of grain.				ins.	lbs. per sq. inch	
lbs.	in.	in. water.	in. water	lbs.		lbs.		lbs.	inches.	inches water.	inches water.	lbs. per sq. inch	lbs.
25	6	4.81	3½	20.132	80.52	4.868	19.48	25	6	4.81	3½	0.03157	9.092
50	12	9.62	6¾	32.147	64.29	17.853	35.71	50	12	9.62	3½	0.11275	32.472
75	18	14.43	7¾	39.291	52.38	35.709	47.62	75	18	14.43	4½	0.15534	44.162
100	24	19.24	8½	45.785	45.78	54.215	54.22	100	24	19.24	5	0.18040	51.955
125	30	24.05	9½	48.058	38.44	76.942	61.56	125	30	24.05	5½	0.19844	57.150
150	36	28.86	9½	51.630	34.42	98.370	65.58	150	36	28.86	2¾	0.21422	61.695
175	42	33.67	10½	53.578	30.61	121.422	69.39	175	42	33.67	6½	0.22550	64.944
200	48	38.48	10½	55.851	27.92	144.149	72.08	200	48	38.48	6¾	0.23677	68.191
225	54	43.29	11½	57.800	25.68	167.200	74.32	225	54	43.29	6½	0.24128	69.490
250	60	48.10	11½	59.100	23.64	190.900	76.36	250	60	48.10	6½	0.24579	70.788
275	66	52.81	11½	59.740	21.73	215.252	78.27	275	66	52.81	6½	0.24805	71.438
300	72	57.62	11½	60.397	20.13	239.603	79.87	300	72	57.62	6½	0.25030	72.087
325	78	62.53	11½	60.397	18.58	264.603	81.82	325	78	62.53	6½	0.25030	72.087

Carried on bottom 60,397 on sides 264,603

Relative vertical and lateral pressures at bottom, when bin is full:

vertical pressure	=	.41943	
lateral pressure	=	.25030	= 1.66,
or lateral pressure equals 59.7% of vertical pressure.			
Coefficient of friction between grain and sides of bin:			
Weight carried by sides	=	264.60	
Total side pressure	=	745.55	= 0.355.

Total Side Pressure .596.184

Relative vertical and lateral pressures at bottom, when bin is full:

vertical pressure	=	.31570	
lateral pressure	=	.18942	= 1.67,
or lateral pressure equals 60% of vertical pressure.			
Coefficient of friction between grain and sides of bin:			
Weight carried by sides	=	279.54	
Total side pressure	=	596.184	= 0.468.

NOTE.—When grain was running out of bin at rate of 50 lbs per min., through opening in center of hopper bottom, the maximum side pressure was 5½/16 ins. water, or 0.200695 lb. per sq. in. This represents 6% increase of pressure due to grain in motion.

Total side pressure .745.552

NOTE.—By sharply tapping bin with hammer the grain settled 3 ins., and gave maximum readings as follows:

Bottom pressure = 13¼ ins. water = 0.47806 lbs. per sq.in., = 21.2% of fluid pressure.
 Side pressure = 7½/16 ins. water = 0.28187 lbs. per sq. in., = 12.49% of fluid pressure.

TABLES OF TESTS ON GRAIN PRESSURE IN MODEL BINS.

MADE BY J. A. JAMIESON, MONTREAL, P. Q., 1903.

TABLE VI.—WHEAT IN WOODEN BIN 12×12 INS. BY 6 FT. 6 INS. HIGH.
Bin made of smooth boards. Weight of grain, 50 lbs. per cu. ft., = 62.2 lbs. per bushel.
Each section of grain weighed in = 6 ins. high, weighing 25 lbs. and having a wall area of 288 sq. ins.
For side pressure, test, first section of grain = 12 ins. high, weighing 50 lbs., wall area 576 sq. ins.; all succeeding sections = 4.8 ins. high, weighing 20 lbs., wall area, 230.4 sq. ins.

TABLE VII.—WHEAT IN ROUND SHEET-STEEL BIN 12 INS. DIAMETER BY 6 FT. 6 INS. HIGH; BOTTOM PRESSURE TEST ONLY.
Weight of grain, 50 lbs. per cu. ft. = 62.2 lbs. per bushel.
Each section of grain weighed in = 7.44 ins. high, weighing 25 lbs. and having a wall area of 280.5 sq. ins. Last section only half as large. 12-in. diameter circular diaphragm horizontally on bottom; = 113.1 sq. ins. area.

Grain weight'd into bin.	Height of grain column.	Equiva. fluid pressure.	Pressure of grain on dia-phragm.	Grain carried on bottom.		Grain carried on sides.	
				Weight.	% of total weight of grain.	Weight.	% of total weight of grain.
lbs.	in.	in. water.	ins.	lbs.		lbs.	
25	6	4.81	33	19.433	77.93	16.833	67.33
50	12	9.62	66	30.824	61.04	23.476	46.52
75	18	14.43	99	36.868	48.49	40.825	54.57
100	24	19.24	132	42.914	40.91	48.43	62.00
125	30	24.05	165	48.963	34.97	56.10	73.36
150	36	28.86	198	55.011	28.97	63.80	83.00
175	42	33.67	231	61.058	23.97	71.44	92.64
200	48	38.48	264	67.106	18.97	79.07	102.28
225	54	43.29	297	73.154	13.97	86.70	111.92
250	60	48.10	330	79.202	8.97	94.33	121.56
275	66	52.91	363	85.250	3.97	101.96	131.20
300	72	57.72	396	91.298	0.97	109.59	140.84
325	78	62.53	429	97.346		117.22	150.48

Carried on bottom 50.656 on sides 274.344

Relative vertical and lateral pressures at bottom, when bin is full:

vertical pressure = $\frac{35178}{21197} = 1.66$,
lateral pressure = $\frac{21197}{274.34} = 0.397$.
or lateral pressure equals 60.3% of vertical pressure.
Coefficient of friction between grain and sides of bin:
Weight carried by sides = $\frac{274.34}{687.11} = 0.397$.
Total side pressure

NOTE.—By sharply tapping sides of bin, the grain settled 2½ ins. and gave a maximum reading of 11½ ins. water, = 20.56% of fluid pressure.
When grain was running out of bin at rate of 120 lbs. per minute through opening in center of hopper bottom, the maximum side pressure was 6½ ins. water, or 0.22775 lbs. per sq. in. This represents 7.5% increase of pressure due to grain in motion.

NOTE.—By sharply tapping sides of bin with hands, the grain settled ¾ ins. from top, and gave maximum reading of 13½ ins. water, = 20.5% of fluid pressure.

TABLE VIII.—SAND IN ROUND SHEET-STEEL BIN 12 INS. DIAMETER BY 6 FT. 6 INS. HIGH; BOTTOM PRESSURE TEST ONLY.

Sharp, clean, Chateaugay River Sand, thoroughly dry, weighing 100 lbs. per cu. ft., angle of repose = 34°. Each section of sand weighed in = 3.63 ins. high, weighing 25 lbs. Last section only half as large. Circular diaphragm 12 ins. diameter, horizontally on bottom; = 113.1 sq. ins. area.

Sand weight'd into bin.	Height of sand column.	Equiva. fluid pressure.	Pressure of sand on dia-phragm.	Sand carried on bottom.		Sand carried on bin-sides.	
				Weight.	% of total weight of sand.	Weight.	% of total weight of sand.
lbs.	ins.	in. water.	in. water.	lbs.		lbs.	
25	3.63	5.82	6½	24.000	96.00	1.000	4.00
50	7.26	11.64	10½	43.356	86.71	6.644	13.29
75	10.89	17.46	13½	65.598	74.13	19.402	25.87
100	14.53	23.28	16	65.290	65.29	34.710	34.71
125	18.15	29.10	18	73.452	58.76	51.548	41.24
150	21.79	34.92	19½	79.573	53.04	70.427	48.96
175	25.41	40.74	20½	84.163	48.09	90.837	51.91
200	29.05	46.56	21½	87.224	43.61	112.776	56.39
225	32.67	52.38	22½	80.284	40.12	134.716	59.88
250	36.30	58.20	22½	91.815	36.72	158.185	63.28
275	39.93	64.02	22½	93.345	33.94	181.655	66.06
300	43.57	69.84	23½	94.620	31.54	205.380	68.46
325	47.19	75.68	23½	95.895	29.50	229.105	70.50
350	50.82	81.48	23½	96.405	27.54	253.595	72.46
375	54.46	87.30	23½	96.660	25.77	278.340	74.23
400	58.08	93.15	23½	97.681	24.42	302.319	75.58
425	61.71	98.95	24½	98.191	23.10	326.809	76.90
450	65.34	104.77	24½	98.446	21.87	351.554	78.13
475	68.97	110.58	24½	98.446	20.72	376.554	79.28
500	72.60	116.40	24½	98.701	19.74	401.299	80.26
525	76.23	122.22	24½	98.956	18.84	426.044	81.16
550	79.86	128.04	24½	99.211	18.45	450.789	81.55

Carried on bottom 99.211 on sides 438.290

Some data taken from *German*
on reinforced concrete grain elevators.

Before the final conclusions are drawn,
some data will be given on reinforced con-
crete grain elevators. This will be taken from
The German by Prof. V. C. Packer.

^{ce} Good examples of reinforced concrete
silos are given, and also formulas for
determining the stresses caused in the walls
of the bins by the pressure of the grain.

There are many things to be learned from
this discussion and drawings given, for
the Germans have for many years made
practical use of reinforced concrete, while
the use of this material in this country
is of comparatively recent date, special-
ly in the construction of granaries.

The Following is Taken from the Beton-Kalender. A German hand-book on concrete and reinforced concrete by J. Jahrgang. 1906.

Translated into English by Prof. N. C. Rice

The bins are generally of rectangular, best of square plan, The walls are naturally under greatest stress at the angles, and are accordingly to be computed with the moment:-

$M = PL^2 \div 12$ or $M = PL^2 \div 24$ if L = side of square. For a rectangular plan sides a and b , the moment at the angles will be:-

$$M = (P \div 12)[a^3 + b^3] \div (a + b)$$

At the middle of b

$$M = (P \div 24)[2a^3 - b^2(3a + b)] \div (a + b)$$

At the middle of a

$$M = (P \div 24)[2b^3 - a^2(3b + a)] \div (a + b)$$

Assuming a uniform pressure on L , a and b for sides exceeding 4.5 meters (14.76 ft.) it may be best to use horizontal beams thus forming rectangular panels, covered by planks or slabs extending vertically. Width of beams in direction of the pressure up to 40 c.m. ($15\frac{3}{4}$ ins.) Thickness of planks or slabs without beams 12 to 24 c.m. (3.05 to 6.1 ins.) or with beam 12 to 16 c.m. (3.05 to 4.05 ins.) Tie rods both ways at middle of walls. The walls form high girders,

which support the floors of the bins and at suitable points rest upon piers.

Slope of the floor less than 45°

Until sufficient additional experiments are available, for the bins likewise is to be assumed a sidewise effect of the pressure of the grain similar to the pressure of earth, taking the angle of repose

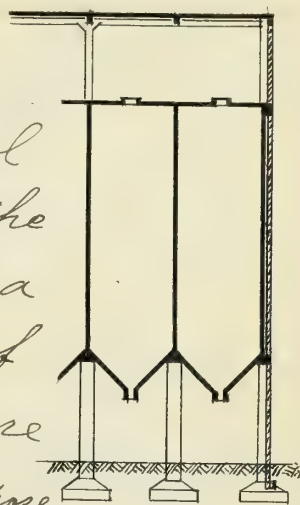


Fig. 2

$\gamma = 45^\circ$ for this pressure. For wheat weighing 760 kilos per cubic meter (47.4 lbs. per cub. ft.) the unit pressure P at a depth h below the top surface of the grain = about $130 h$ in kilos per sq. met.

(Let h = this depth in ft., the $P = 26.7 h$ in lbs. per sq. ft.)

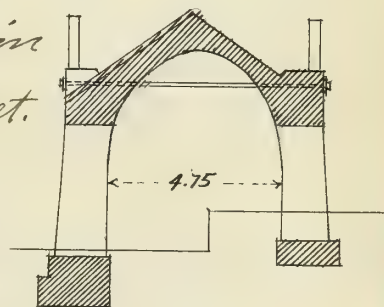


Fig. 3

Note - See Eng. Record of Oct. 7, 1905,

page 401, where in a bin 10.8 ft. square and 65.6 ft. deep, a maximum pressure on the bottom of $\frac{1}{4}$ kilos per sq. c. m. was obtained (511 lbs. per sq. ft.)

The entire contents are to be taken for the load on the bottom, with some allowance for impact. According to Janssen, the actual pressure on the bottom is much less, when in a state of repose.

In construction of bins of great dimensions it is relatively cheap to build them of previously made cement blocks with inserted iron rings.

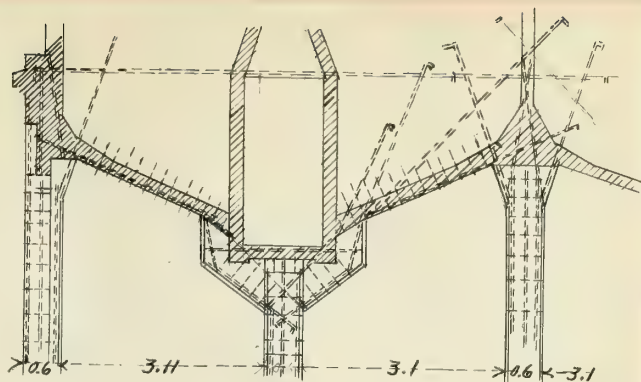


Fig. 4

How little suitable for these structures may be any other material than reinforced concrete is shown by fig. 3, the original project for the Hartstein-Industrie

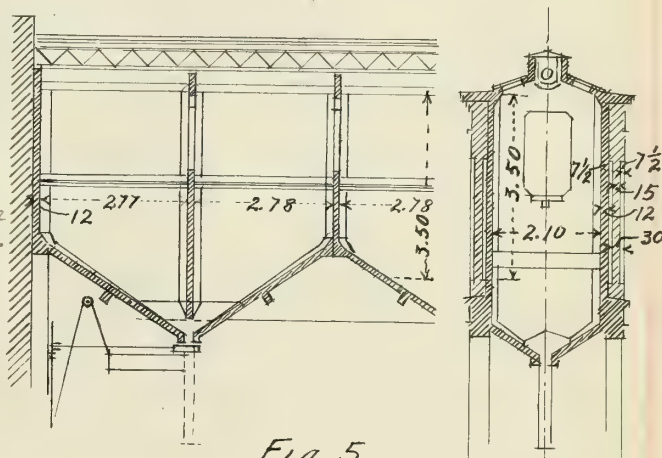


Fig. 5.

Gesellschaft (Hardstone Mfg. Assocn.) in Oberharzstadt. For the construction in concrete see 'Lion' for 1903, part 1, plate 4. Some details of the reinforcement of a large structure are represented in fig. 4. Next in value, Lion for 1903, part 1, plate 4, shows the construction of a bin in concrete. Finally is an example of a small structure in concrete, a grain elevator to contain 20 cu. met. 2927 cu. ft. built by the Hartstein-Industrie. On account of its small size it should be

tioned, an elevator built by "the local Co." in concrete - steel for a large mill in Lima in Posen. The local conditions demand the best possible localization of the site, and for this purpose, concrete steel offered itself as the most suitable material by its light weight and ease of the work. The area of plan available for bins, 38.5×11 met. 125×35 ft. was divided into $7 \times 2 = 14$ squares with sides 5.5 met. 18.5 ft. each. The total height of the structure amounts to 27 met. (79 ft.) and it can hold about 6000 tonnes, 6000 tons, of grain at one time. It is particularly favorable can secured here for concrete-steel because the building will be very fast.

For the other buildings of the station, most of the concrete was spent for foundations, but for this was provided a concrete bed of about 5.5 met. (17 ft.) in thickness, which under the most unfavorable conditions of loading has shown its perfect capacity of resistance.

The following was translated from the
 Greek by Prof. W. R. Inge from the 1st
 volume of the *Enchiridion* by Origen.

Teachers are accustomed for holding
 any materials on boxes, such as paper,
 and canvas, or leather, etc. where
 by reason of the slant-like arrangement,
 the materials slumped in from above may
 be drawn off at need at the same point
 of the bin. We require to structural treat-
 ment, as distinguished before, just bin, with
 out separate divisions or which have any
 discontinuities. But in comparison with
 this height, and the structure with bin
 as shown, as called, properly, where a
 separate bin are not necessary, better than
 as now designed.

As an example of the first kind without
 internal divisions, we give in fig.
 212 a section and plan of a coal bin as
 in the first sketch.

The second kind may be described as having
 separate openings, directly to the bins for
 access. The walls throughout the entire length
 of the container, materials, and the openings

direction, to the south, which are anchored to the bottom, to the same position, 4.5 ft. - 5. (1.48 ft. sq. and together at the top). The view of the entire design is given in fig. 22.

The illustration for the Unimproved Standard manufacturing process transition from the preceding kind to the same in structure. The kind of concrete section under pressure are arranged in pairs - each along the length of the building, and they serve for absorbing broken packing of different sizes of pieces. The structure was fully described in 1913, of the Journal, and was done, by the author, with 12 plates, in which reference is here made.

The most elevation for the same type, at Munich, has been 2.5 x 3.75 - 4 ft. in 15 ft. 11.5 x 12.3 ft. (10.5 net depth 54.2 ft.) and each containing 2200 cubic ft. (6,500 bushels).

The intersections of the bin walls are supported by concrete-steel columns, which transmit the considerable load to a concrete-steel foundation. The material is 12 ft. thick so that 2.5 ft. high pump can be placed on the same without. The vertical walls are made of concrete.

- which is, these panels are covered with
 buckram. Between them and the concrete
 walls of the bins is left an insulating air space.
 The bins empty into a small concrete chute
 which runs through the bin house. This chute
 is at the height of the top of the
 bins. While under ordinary conditions
 the bins are covered with a
 canvased pyramidal, the great volume
 of the concrete wood drips of a well
 man factory (Fig. 210, show the supports
 supported by a series of beams and
 with stiffeners in water built in, like
 were the external walls 8 meters apart
 (26.2 ft.) are connected by the top of the girder
 at the middle of the panel. The wall was
 in the external wall, then chiefly in
 a vertical direction between the two hori-
 zontal wall girders. Figs. 217 and 218
 give a perspective view of this elevator,
 which is built on a high rock outcrop.
 Fished girders are employed as roof beams
 and endowing beams reinforced concrete
 may be doubtless be termed the building
 material most suitable for elevators, for
 aside from its incomparability, the

fixing of the walls across them together in the vertical plane. The favorable circumstance is to be considered, that both functions of the horizontal inserted steel bars in the bin walls are not required at the same time; the forces produced by the anchoring are greatest when adjacent bins are filled, but bending stresses do not then occur, and with maximum bending stresses when alternate bins are full. The anchoring stresses are reduced one half. The structural advantages of concrete-steel have also caused it to have an increasing use in the construction of large elevators during recent years. We further give some examples of elevator buildings erected by the firm of Wägers & Freytag in this year and the past year.

Fig. 221 gives a view of the inserted steel rods in the hoppers of the elevator with 7 hexagonal bins 10 meters high (52.5 ft.) for the Eisen (Portland) Cement Works in Bielefeld.

Since the walls of square bins, under every condition of ^{the} filling of adjacent cells, are to be considered as perfectly fixed at the angles, then the moment at the middle

of the side is $FL = 24$, and at the angles is $FL = 12$. Hence the thickness of the walls will properly be made twice as great near the angles as at the middle. In fig. 218 is shown the reinforcement of the walls of a silo with 44 bins 4.0 meters square with angles for the Olsen Portland cement made in Hoboken; the thickness of the walls is evidently doubled at the angles. The exterior walls are faced with a brick wall which however is left open at the angles and the concrete is left exposed, and it is supported on concrete footings having beams extending at certain intervals.

The view of the two elevators with 7 hexagonal cells in each is shown in fig. 220. The name is the tower of the Lehigh Cement Co. in case of the open bins.

Like most of smelting works many concrete structures find their construction and a place of construction for containing ore and coal. We give in figs. 222 and 223 transverse and longitudinal sections of such an elevator, whose length amounts to 186 meters (610 ft.). The inclined bottom, sup-

- (iii) are supported by very strong transverse girders which are the concrete pillars supporting the steel railway track. On account of the great length of the design, four expansion joints were provided.

The reinforcement of the transverse girders must be specially arranged to resist shearing stress. Fig. 224 shows the transverse section of a design serving the same purpose for the smelting works, Knuß Hingen, in Lorraine. The walls and floor of the underground passage are likewise executed in concrete (iii). The transverse walls are spaced at intervals of ± 20 m. (132 ft.) and together with the inclined bottom surfaces, at their outer parts are on separate concrete foundations. The raising bridge, which supports the supply track, in this design, likewise consists of reinforced concrete and is calculated for the loading of the Prussian Main Railway.

Very important for the designing of elevators is a knowledge of the side pressure exerted on the walls by the contained material. For very large bins without transverse walls, or for those with very large se-

- triangular bins, the calculations are made according to the formula applicable to the pressure of the earth. Neglecting the friction on the walls, the total side pressure to depth h is:

$$P = \frac{1}{2} \cdot \gamma \cdot h^2 \tan^2(45^\circ - \frac{\phi}{2})$$

And the pressure on a unit area of surface at the depth h is:

$$P = \gamma \cdot h \cdot \tan^2(45^\circ - \frac{\phi}{2}) \text{ in kilos per square meter.}$$

In American units this should have the same form, for $\tan^2(45^\circ - \frac{\phi}{2})$ converted thereon.

For the different materials we have the following table:—

Material	γ kilos per cub. met.	ϕ° in degrees	P kilos per sq. met.
Gas coke	800 to 900	45° to 50°	146 h
Cement	1400	40°	305 h
Broken stone	1600 to 1800	45°	290 h
Malt	530	22°	240 h
Wheat	760	22°	345 h

γ = weight of material. ϕ° = angle of repose. P = exerted pressure

In American Elevators.

Material	γ lbs. per cub. ft.	ϕ degrees	P lbs. per sq. ft.
Gas coke	49.8 to 56	45° to 50°	9.8 h
Cement	87.2	40°	20.5 h
Broken stone	99.8 to 112.0	45°	19.5 h
Malt	33.0	22°	16.1 h
Wheat	47.4	22°	23.2 h

In elevator bins of great height, according to these values, quite large pressures are exerted on the lower portion, and one is justified in taking into account the most favorable effect of the friction of the contained materials on the surface of the walls. As to the accurate determination of the side pressures in elevator bins, these two publications; by Koseoff in *Zeitschrift für Bauwesen*, 1876 page 496, and by Koseoff in the *Zeitschrift des Vereins Deutscher Ingenieure*, 1896 page 1046; both substantially agree with each other. If the friction of the contained materials on the perimeter of the walls be considered, it is shown that the

side pressure cannot exceed a certain limiting value, P_{max} . This limiting value will then occur when the weight of the layer equals the frictional resistance of its perimeter, so that for a square form with side squares S in length,

$$P_{max} \cdot f \cdot dh \cdot 4S = \gamma \cdot S^2 \cdot dh \quad \text{Hence it follows:}$$

$$P_{max} = \gamma \cdot S \div 4f$$

f = coefficient of friction between the contained materials and the bin walls, which may be placed at $\frac{1}{3}$ or $\frac{1}{4}$. Concrete-lined walls are mostly not plastered and give greater values of f , i. e., have less side pressure than smooth wooden walls, and they are preferable on this account.

The calculation of the different values, according to the grain publications, then occurs in detail, the following simple method being therefore recommended. Beginning at the top, the side pressures P are computed by the formula:

$$P = \gamma \cdot h \cdot \tan(45^\circ - \frac{\phi^2}{2})$$

Until at a certain depth in fact, the value

$$P_{\max} = \frac{\gamma \cdot s}{4 \cdot f}$$

which is then to be taken as constant from then downwards. Besides simplicity, this method of calculation affords great security, indicated the same, since experiments have shown, that the materials in motion exert a greater pressure on the walls, than occurs in a state of rest. *

The greatest attainable pressure on the bottom, N per unit of area, may be computed from the greatest side pressure. This is:

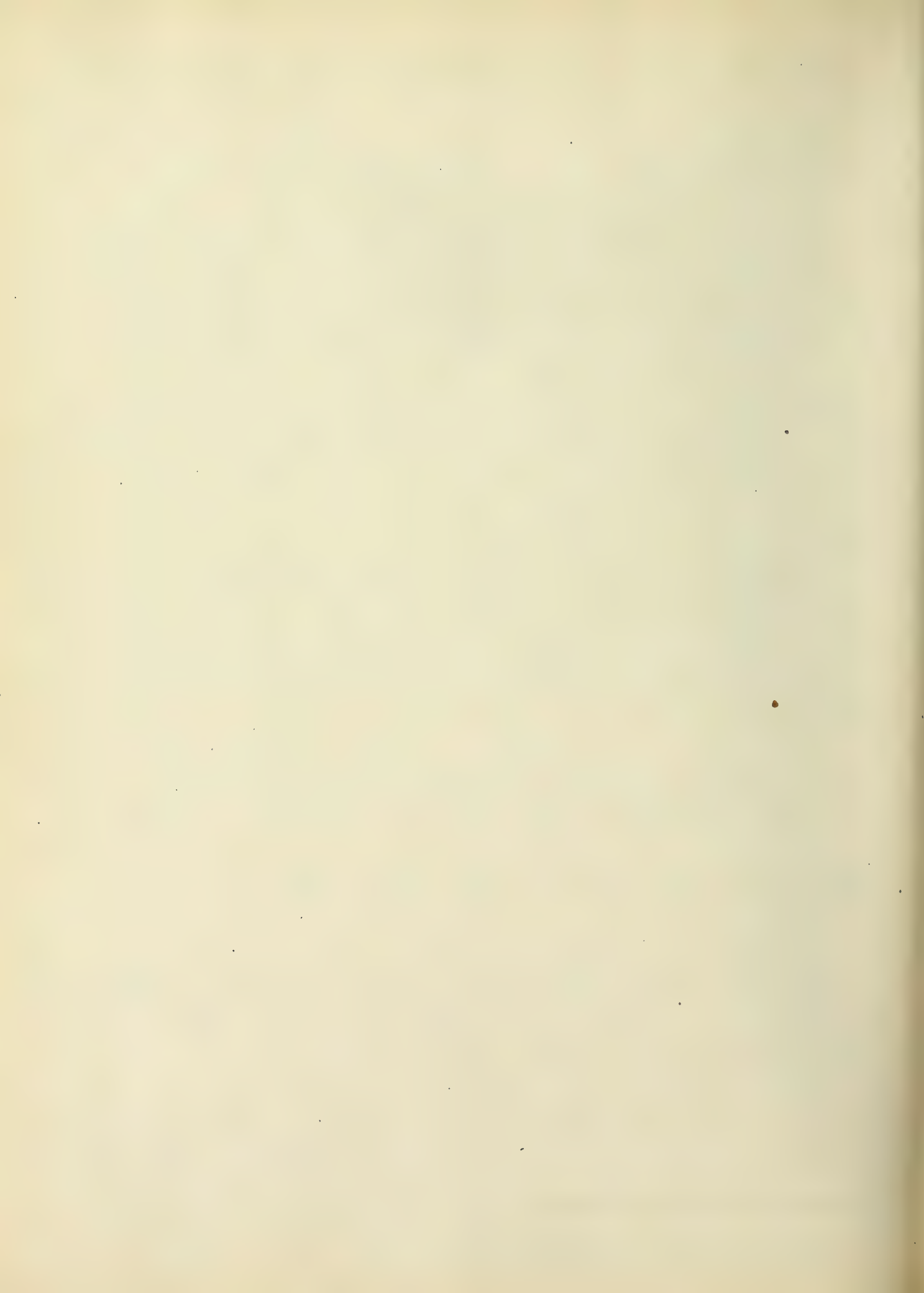
$$N \cdot \tan^2(45 - \frac{\phi}{2}) = P_{\max}.$$

Thence: $N = P_{\max} \div \tan^2(45 - \frac{\phi}{2})$

If we wish to proceed with entire safety, the entire contents of the bin may be taken as the load acting on its bottom.

For small depth bin this weight will be

* In later experiments it was demonstrated that the increase of lateral pressure owing to grain in motion was very small, less than 5%. See page?



less than the greatest pressure N on the bottom, since strictly taken, this, as well as P_{max} only occurs at an infinite depth.

If the ground plan of the bin differs from the square, the bending moments can no longer be computed as,

$$Pl^2 \div 12 \text{ and } Pl^2 \div 24$$

If the plan be a rectangular with width b and length l , then by the law of virtual velocities or by the formula of the continuous solid girder, the bending moment, at the angle is:

$$M = P(l^3 + b^3) \div 12(l + b)$$

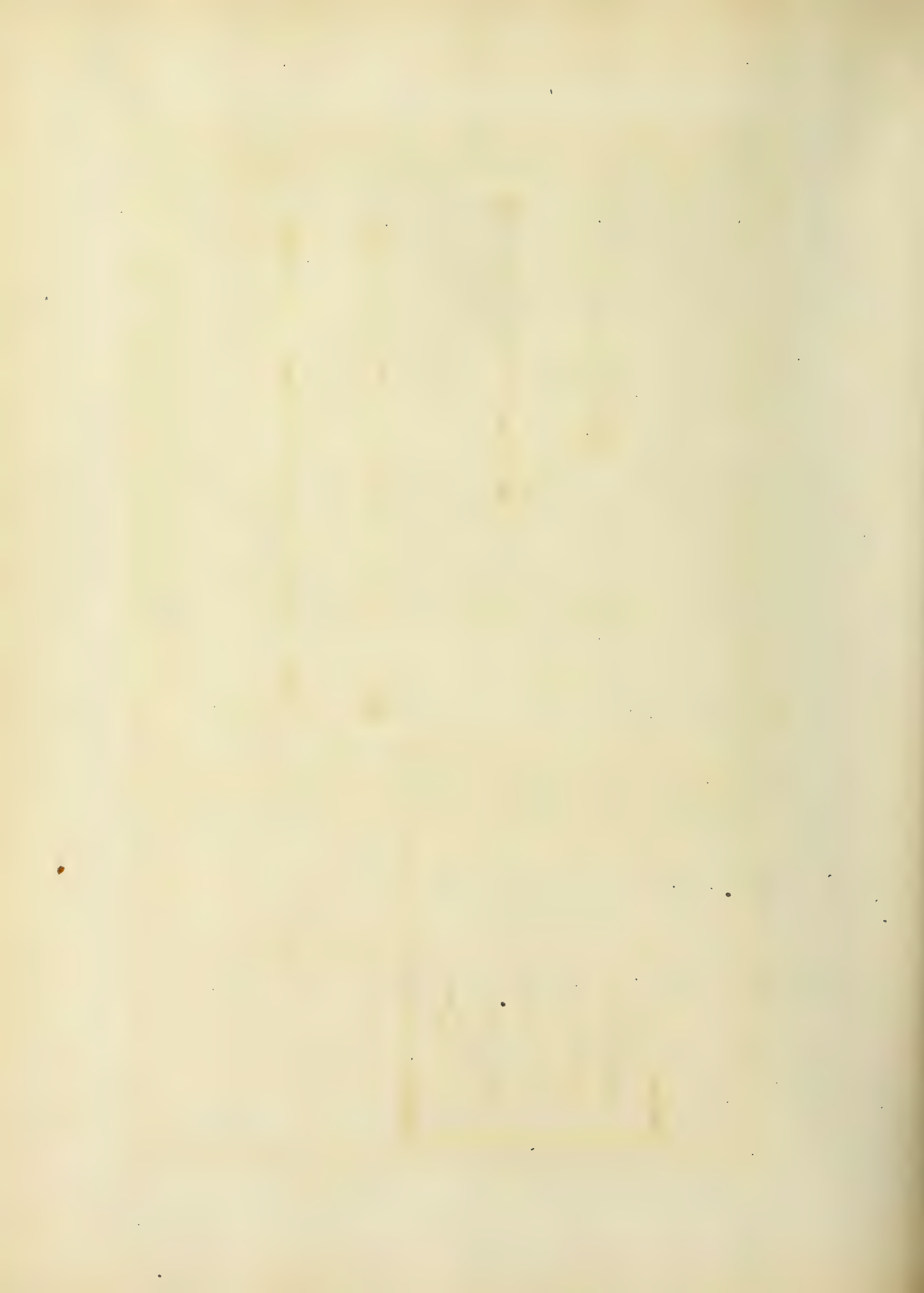
and at the middle of the side l is:

$$M_l = \frac{Pl^2}{8} - \frac{P}{12} \times \frac{l^3 + b^3}{l + b}$$

and at the middle of the side b :

$$M_b = \frac{Pb^2}{8} - \frac{P}{12} \left(\frac{l^3 + b^3}{l + b} \right)$$

These formulas are deduced under the assumption, that both walls are of equal thickness, and that the corner may be neglected, which the walls of adjacent bins oppose to deformation.



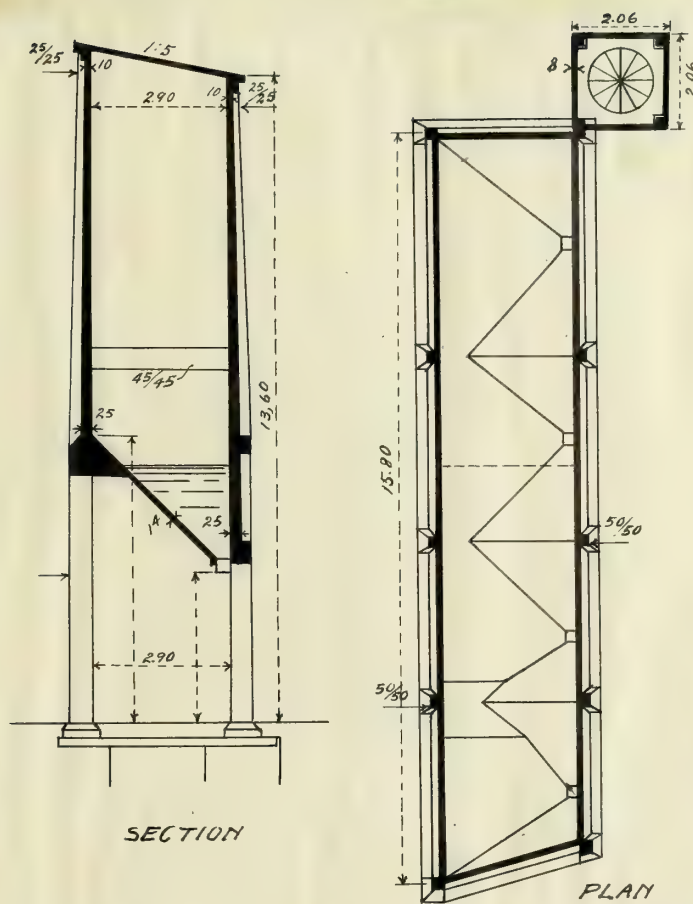
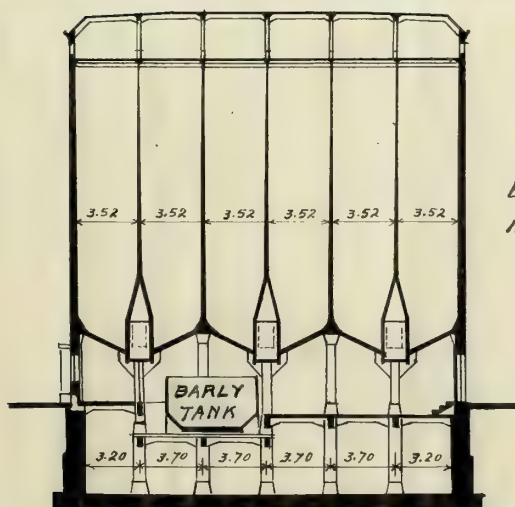
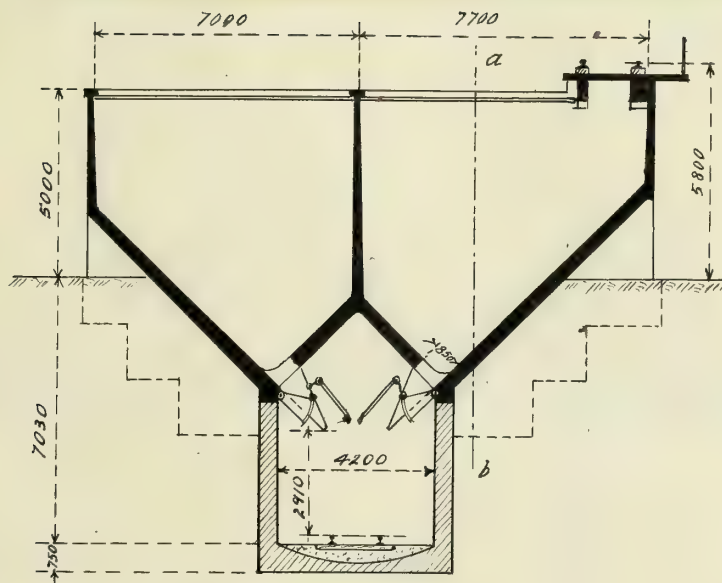


FIG. 212. COAL BIN IN KIRN a.N.

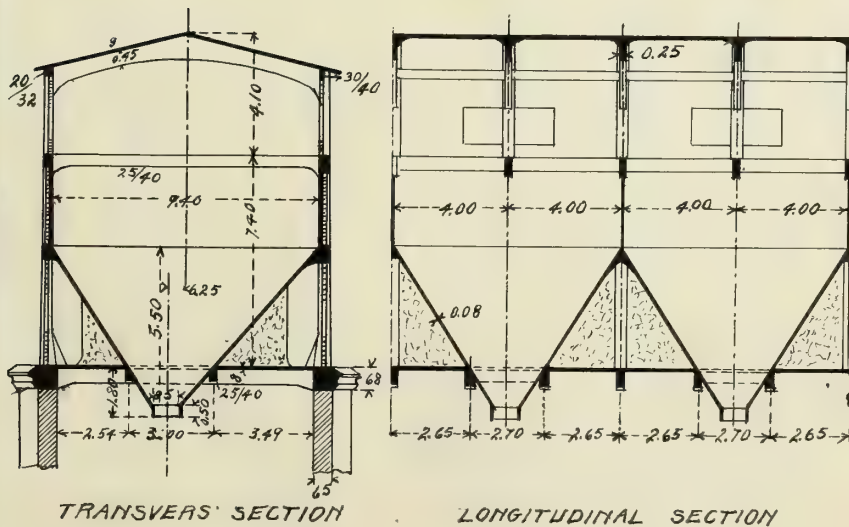


BIN FOR MALT
IN MUNICH.



ORE BIN FOR SMELTING WORKS AT HUTTEN

FIG. 224



BIN FOR SHAVINGS IN A CELLULOID MANUFACTORY

FIG. 216

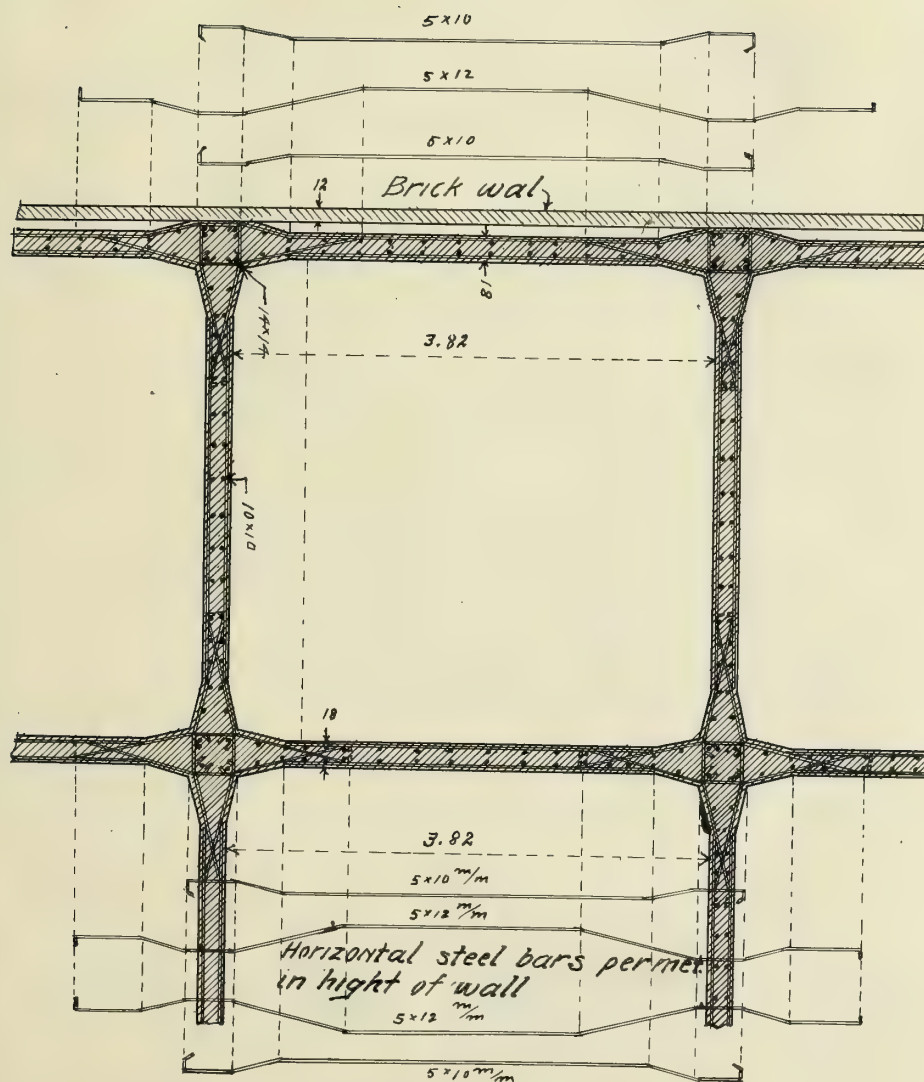


FIG. 219. DETAIL OF THE REINFORCEMENT OF A BIN FOR CEMENT AT ITZENHOE.

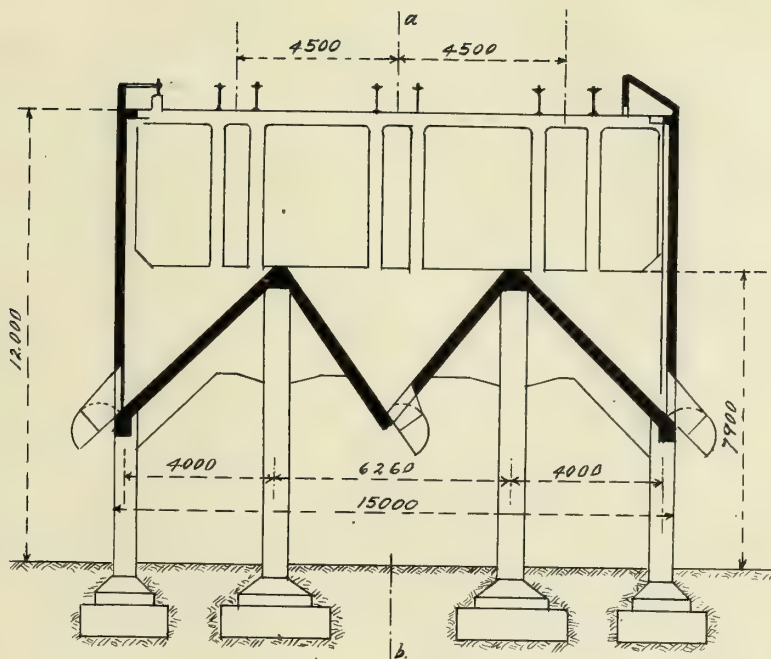


FIG. 222. CROSS SECTION

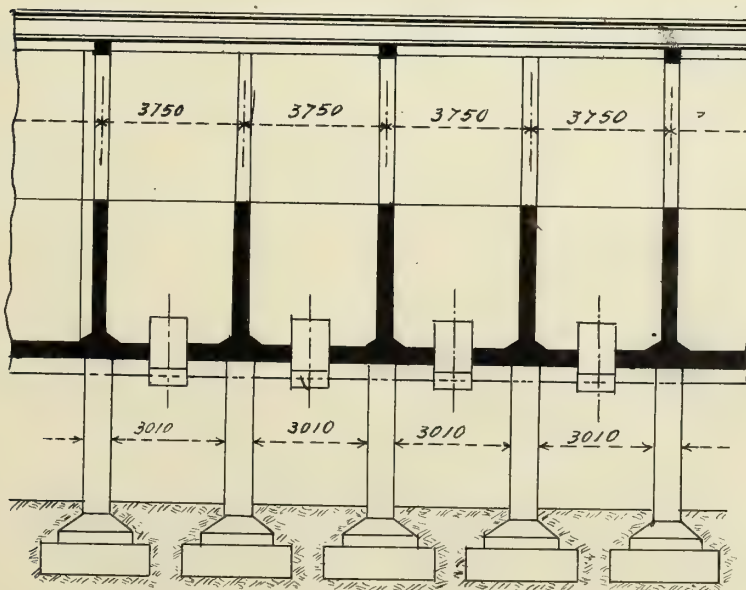


FIG. 223. LONGITUDINAL SECTION

ORE BIN FOR SMELTING WORKS IN LORRAIN

IV

Conclusions

Wooden Elevator Construction. - The time of the wooden elevator is past. One of the most important reasons for the use of wood in the construction of elevators was the low price of this material, but now that the cost of lumber is so high, there is no excuse at all for the use of wood in this kind of structures, especially when the danger from fire is so great, which makes insurance rates prohibitive.

The wooden elevator has, however, some great advantages over all others: It is very easily built at any time of the year, and lumber is easily obtained at any time and anywhere. But, as I said before, we should not use wood in the construction of elevators, for the reason, above all, of its great danger from fire.

Steel Elevators. - The steel construction has the advantage of being the lightest one per bushel of storage, of great flexibility in case of any derangement, workable in all seasons and places, and if built iso-

lated from other buildings, a steel structure is practically fire proof. It necessitates, however, more & less care in its preservation from rust on exposed surfaces, and if built adjacent to inflammable buildings, it must be covered with protecting walls of masonry. It might also be said against steel construction that, if not protected by masonry walls, the steel frame will be subjected to great changes in temperature.

There is one feature, however, of a steel elevator building not possessed by any other, and that is, it may be at any time dismantled and removed without materially impairing its value.

Brick Construction.—The most powerful argument against the use of brick construction is the great weight and volume of the brick walls. This kind of construction cannot be very easily enforced by the water works of any design are used, and it can be conveniently built only during the warm months of the year. Unless the brick walls are built with an air space, this construction will

must protect the grain from moisture.

The greatest advantage of a brick elevator is, that it is fire proof, and that this material is easily obtained almost anywhere.

Hollow Tile Construction.— There is no doubt that hollow tile is one of the most suitable materials for the construction of elevators, on account of its tightness, its great resistance to the destructive action of heat, its capability to keep out moisture, and on account of the fact that it lends itself to be easily reinforced by steel.

Hollow tile is not easily obtained, but in certain parts of the country, however, and is an expensive material. Besides, the use of hollow tile construction is somewhat restricted by patents, unless some original type of construction be devised and used.

Reinforced Concrete Construction.— The reinforced concrete is, in my opinion, the most suitable material for grain elevators; it is incombustible, it adapts itself to any form or type of construction, and it possesses

great compressive strength. Concrete walls easily built with an air space, which fact enables the lin to protect the grain from moisture. This construction is, however, restricted more than any other to the warm months of the year. Concrete is also a very heavy material, and quite expensive.

Chapter Best Adapted to Future Conditions. — After making a careful study of the requirements of a grain elevator, and after, studying in detail and comparing the advantages and disadvantages of the different materials that are used in the construction of this kind of structures, I am of the opinion, as I already said on another page, that reinforced concrete is the most adaptable material. It is the material of the future. When we work with reinforced concrete, we are no longer restricted to the use of blocks of a fixed size and shape, as in the case of bricks or tiles, but we have a material which we may mold into any shape or form, thus facilitating the construction to a very great extent. The use of concrete affords the engineer a broader field for applying his

originality, and it enables him to design a structure which will more nearly satisfy all the requirements for the shape of the building in general, as well as for efficient and economical details.

By the courtesy of Messrs. Barnett & Record, grain elevator engineers of Minneapolis, Minn., I am able to add the following blue prints and photographs. The photographs show some of the grain elevators built by the Barnett & Record Co. The blue prints show details of the construction of these elevators, and also a report on some fire tests of tiles used by the above mentioned engineers in their constructions. These tests, which show to what extent these tiles resist the action of heat, are of great value, for tile is so much used now in all kinds of fire proof structures.

71

Fire Test

THE JOHNSON-RECORD — SYSTEM

OF Fire-Proof Tile Grain Construction for Bins —

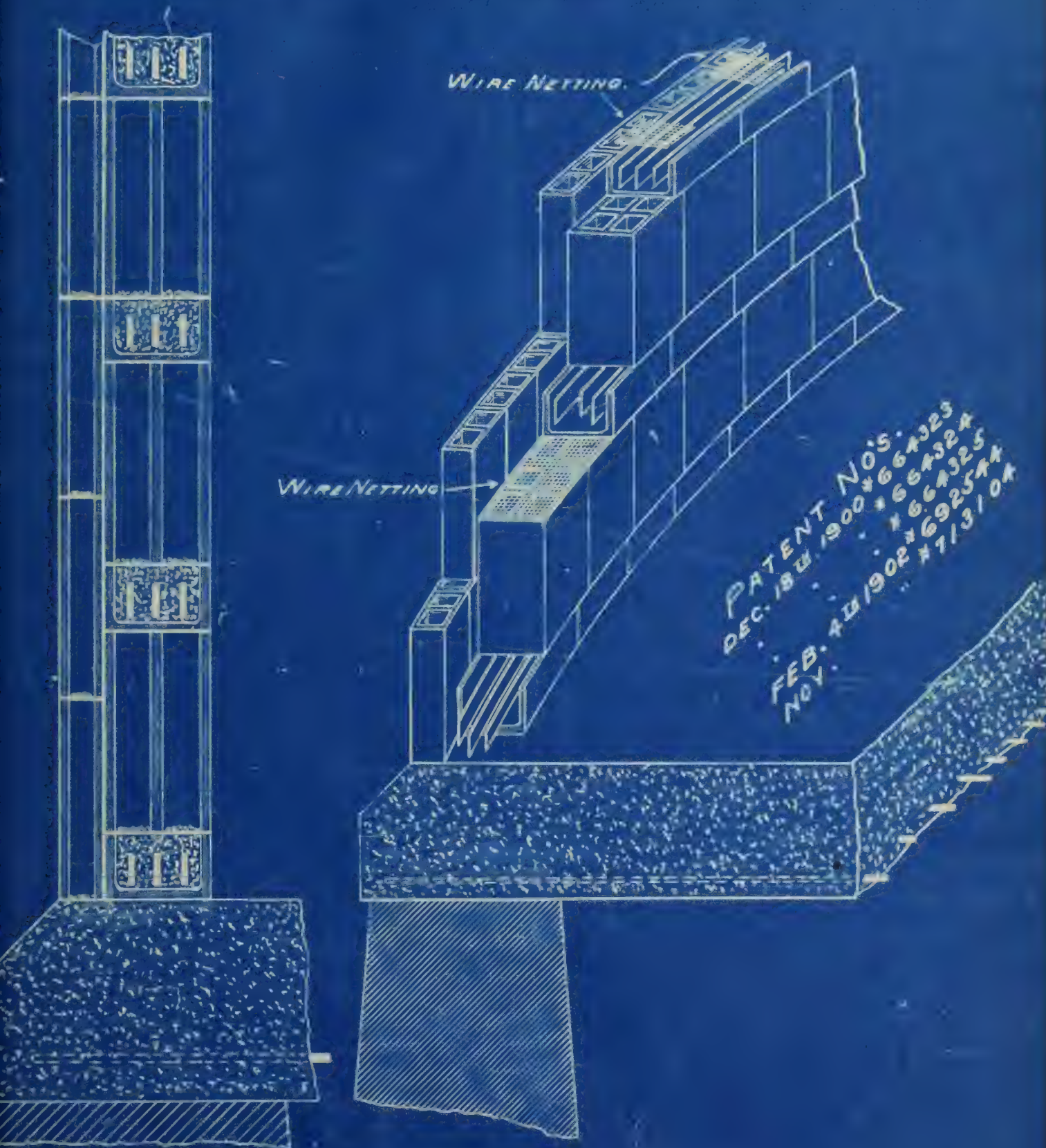
THE BARNETT ^{and} RECORD CO. ^{Mpls. Minn.}

145 T 217

HIT 145

ENGINEERS & CONTRACTORS.

MINNEAPOLIS, MINN.

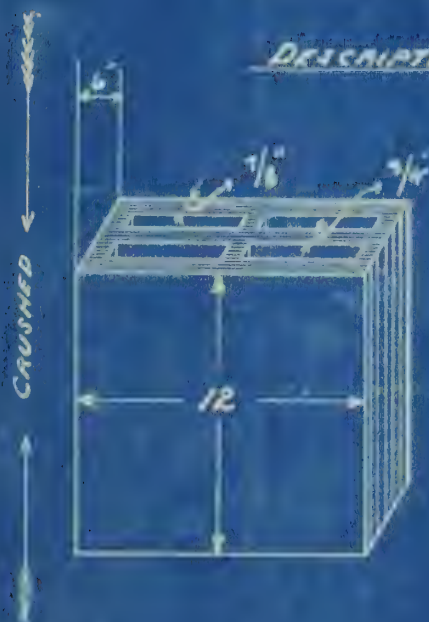


PATENT NO'S.
DEC. 18TH 1900 *664323
FEB. 4TH 1902 *664325
NOV. 11TH 1902 *692544
FEB. 11TH 1904 *713104

JOHNSON-RECORD SYSTEM
OF
FIREPROOF TILE GRAIN BIN CONSTRUCTION

JULY 27TH, 1900.REPORT OF TESTS OF FIREPROOFING TILE.MADE FOR E. V. JOHNSON COMPANY, 34 & 35 HARTFORD BUILDING, CHICAGO.BY THE PITTSBURGH TESTING LABORATORY, LIMITED.
PITTSBURGH, PA.

<u>AREA</u>	<u>ACTUAL LBS.</u> <u>PRESSURE</u>	<u>PRESSURE PER</u> <u>SQ. INCH.</u>	<u>REMARKS</u>
38.75	460200	11880	BROKE IN SMALL FRAGMENTS WITH NO WARNING.

DESCRIPTION OF PIECE OF TILE TESTED.

(SIGNED)

PITTSBURGH TESTING LABORATORY,

BY JOHN M. BAILEY,
SEC'Y.

JULY 27th, 1900.REPORT OF TESTS OF FIREPROOFING TILE.MADE FOR E. V. JOHNSON COMPANY, 84 & 85 HARTFORD BUILDING, CHICAGO.BY THE PITTSBURGH TESTING LABORATORY, LIMITED.
PITTSBURGH, PA.

<u>AREA</u>	<u>ACTUAL LBS.</u> <u>PRESSURE</u>	<u>PRESSURE PER</u> <u>SQ. INCH.</u>	<u>REMARKS.</u>
41.12	110500	2690	TILE CRACKED ON ONE SIDE ONLY, AS PER SKETCH. NO SIGNS OF CRACKING BEING VISABLE UNTIL CRUSHED.

DESCRIPTION OF PIECE OF TILE TESTED.

(SIGNED)

PITTSBURGH TESTING LABORATORY,

BY JOHN M. BAILEY,

S'Y.

JULY 27TH, 1900

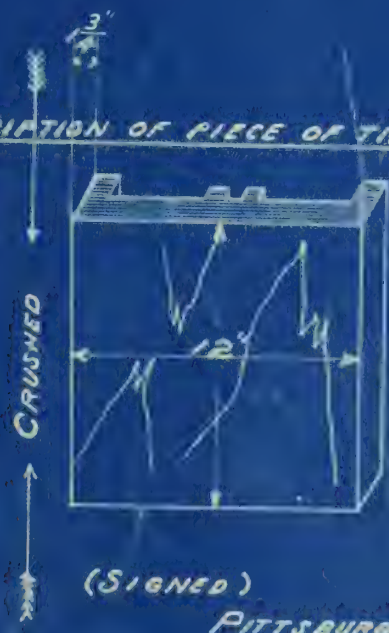
REPORT OF TESTS OF FIREPROOFING TILE

MADE FOR E. V. JOHNSON COMPANY 84 & 85 HARTFORD BUILDING, CHICAGO.

BY THE PITTSBURGH TESTING LABORATORY, LIMITED.
PITTSBURGH, PA.

<u>AREA</u>	<u>ACTUAL LBS.</u> <u>PRESSURE</u>	<u>PRESSURE PER</u> <u>SQ. INCH.</u>	<u>REMARKS.</u>
12.88	104000	8070	BROKE WITH SEVERAL ANGULAR FRACTURES SPLITTING FROM TOP TO BOTTOM GIVING SLIGHT WARNING BEFORE BREAK

DESCRIPTION OF PIECE OF TILE TESTED

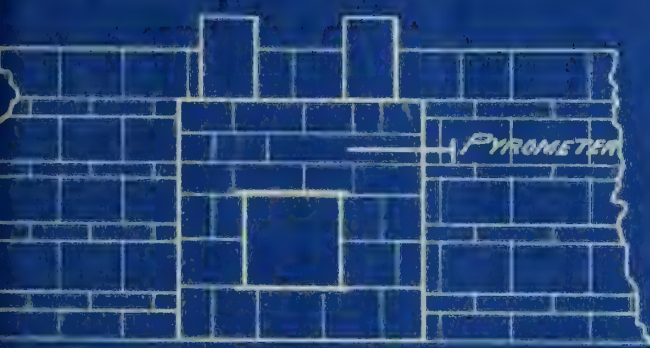


(SIGNED)

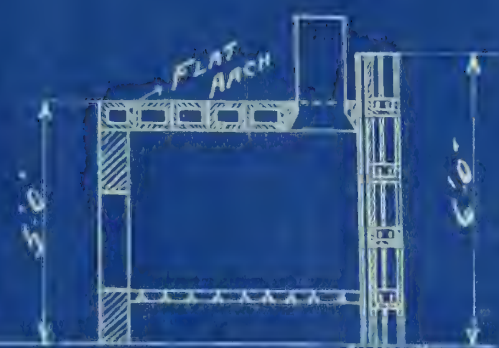
PITTSBURGH TESTING LABORATORY, LTD.,

BY JOHN M. BAILEY.

SECR.

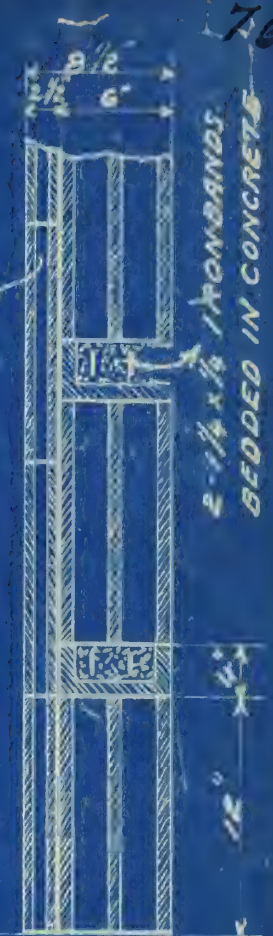


ELEVATION

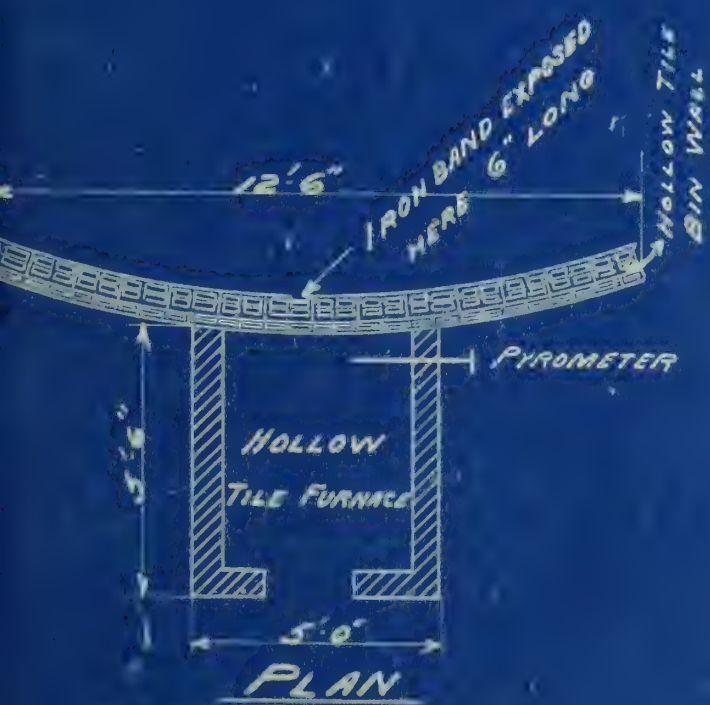


SECTION

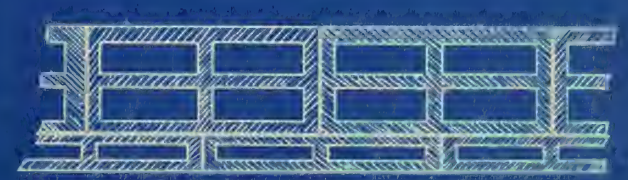
OUTSIDE
OR
FIRE
SURFACE



DETAIL SECTION



PLAN



DETAIL PLAN BIN WALL

HOLLOW TILE GRAIN BIN

Fire Test Dec. 28th 1900.



EXTRACTS FROM REPORT OF FIRE TESTS BY HARRY E. SMITH-CONSULTING ENGINEER.

MINNEAPOLIS, MINN. DEC. 31, 1900.

MESSRS BARNETT & RECORD CO.,

306 CORN EXCHANGE,

CITY.

GENTLEMAN:

I BEG LEAVE TO SUBMIT THE FOLLOWING REPORT UPON A TEST MADE TO DETERMINE THE HEAT RESISTING PROPERTIES OF A SECTION OF HOLLOW TILE GRAIN BIN, BUILT TO CORRESPOND TO YOUR NEW METHOD OF HOLLOW TILE ELEVATOR CONSTRUCTION.

IN ORDER TO MAKE THE TEST AS PRACTICAL AS POSSIBLE, SOME FOUR WEEKS AGO A SECTION OF WALL WAS CONSTRUCTED, THE DETAILS OF WHICH ARE SHOWN IN THE ACCOMPANYING BLUE PRINT, TO CORRESPOND TO THAT WHICH COULD BE CONSTRUCTED FOR A 45 FOOT DIAMETER GRAIN ELEVATOR STORAGE BIN. AGAINST THIS WAS BUILT AN OVEN OR FURNACE, IN WHICH BY MEANS OF FIRE, THE NECESSARY HEAT COULD BE BROUGHT TO BEAR UPON THE OUTER WALL OF THE EXPERIMENTAL BIN.

A PYROMETER TUBE WAS INSERTED NEAR THE TOP OF THE FURNACE AND ABOUT SIX INCHES FROM THE PORTION OF THE WALL TO BE TESTED AND DIRECTLY IN THE PATH OF THE HEATED FLAME AND GASES WHICH IMPINGED ON THE WALL. (SEE BLUE PRINT.) THE PYROMETER WHEN THUS LOCATED WAS BELIEVED TO SHOW THE TEMPERATURE TO WHICH THE WALL WAS SUBJECTED.

ON THE DATE OF THE TEST THE TEMPERATURE OF THE OUTSIDE AIR WAS 15 DEGREES ABOVE ZERO. ON THE INSIDE OF THE WALL AT THE LOCATION OF THE EXPOSED IRON BAND IN THE WALL, SOME SNOW WAS PACKED AGAINST THE BAND AND A NUMBER OF PATCHES OF SNOW WERE PLACED UPON THE TILE WALL ITSELF, IN ORDER TO OBSERVE THE EFFECT OF THE TRANSMITTED HEAT THROUGH THE WALL.

A FIRE WAS STARTED UPON THE GRATE OF THE FURNACE AT 15 O'CLOCK AND THE TEMPERATURE OF THE FURNACE RAPIDLY ROSE TO 800 DEGREES FAHR.

AFTER THE FIRE HAD BURNED ITSELF OUT SUFFICIENTLY THE BIN
ALL OF THE FURNACE WAS CAREFULLY EXAMINED AND NO TRACE OF A CHECK
CRACK COULD BE FOUND.

IN VIEW OF THE FACT THAT THE FIRE HAD BEEN CONTINUED FOR TWO
AND ONE-HALF HOURS, THE HEAT TO WHICH THE WALL WAS SUBJECTED
CORRESPONDED, IN MY OPINION, CLOSELY TO THAT WHICH WOULD BE PRO-
VIDED BY THE BURNING OF A WOODEN STRUCTURE BUILT AGAINST THE SIDE
OF AN ACTUAL GRAIN BIN OF THIS DESCRIPTION.

THE RESULTS OF THIS TEST SEEM TO INDICATE THAT THIS KIND OF CON-
STRUCTION FOR GRAIN STORAGE WOULD WITHSTAND ANY ORDINARY EXTERNAL
HEAT DUE TO ADJACENT FIRES AND WOULD AT THE SAME TIME ALSO PREVENT
UNDUE TRANSMISSION OF HEAT TO THE GRAIN STORED WITHIN.

RESPECT FULLY SUBMITTED,

HARRY E. SMITH,

CONSULTING ENGINEER.

TIME	TEMPERATURE
30 P.M.	500 DEG. FAN.
37	600
38	700
38½	800
39	900
39½	1000
40	1100
41	1200
42	1250
44	1270
46	1200
50	1150
51	1200
52	1250
54	1300
55	1330
56	1350
57	1365
59	1390
59½	1400
01	1440
02	1470
03	1500
04	1540
05	1570
06	1620
07	1700
09	1800
10	1900
10½	1950
11	2000

« THIS TABLE SHOWS THE TIME AND CORRESPONDING TEMPERATURE DURING THE NEXT 41 MINUTES OF THE TEST.

AS THE LIMIT OF THE PYROMETER WAS 2000 DEGS.* THE INSTRUMENT HAD TO BE REMOVED WHEN THIS TEMPERATURE WAS REACHED. THE ACTUAL TEMPERATURE OF THE FURNACE WAS, NO DOUBT, CONSIDERABLY ABOVE 2000 DEGS. AT THE MAXIMUM.

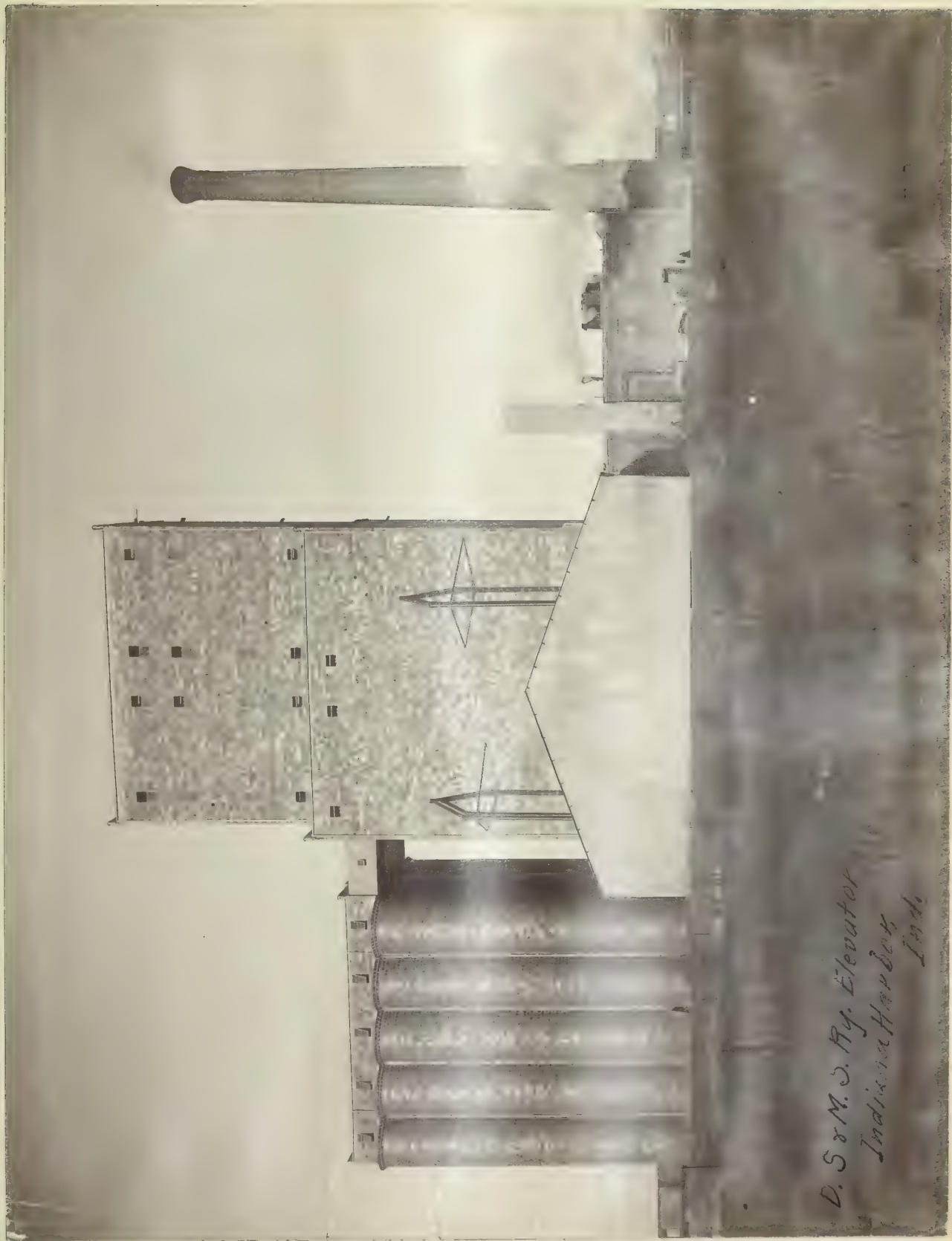
AT THE MAXIMUM HEAT A SOLID BALL OF FLAME ROSE TO A HEIGHT OF ABOUT TWO FEET ABOVE THE TILE CHIMNEYS AND FLAME WAS ALWAYS VISIBLE DURING THE GREATER PART OF THE TEST.

THE SNOW THAT WAS PACKED AGAINST THE EXPOSED IRON BAND ON THE INSIDE OF THE WALL BEGAN TO SHOW SIGNS OF MELTING AT 4-09 O'CLOCK WHEN THE TEMPERATURE OF 1800 DEGS. HAD BEEN REACHED, AND, AT THE END OF THE TEST A SMALL AMOUNT OF SNOW STILL REMAINED AT THIS POINT. THE PATCHES OF SNOW ON THE INTERIOR OF THE WALL SHOWED NO SIGNS OF MELTING AT THE END OF THE TEST.

* This is the temperature at which cast iron melts.

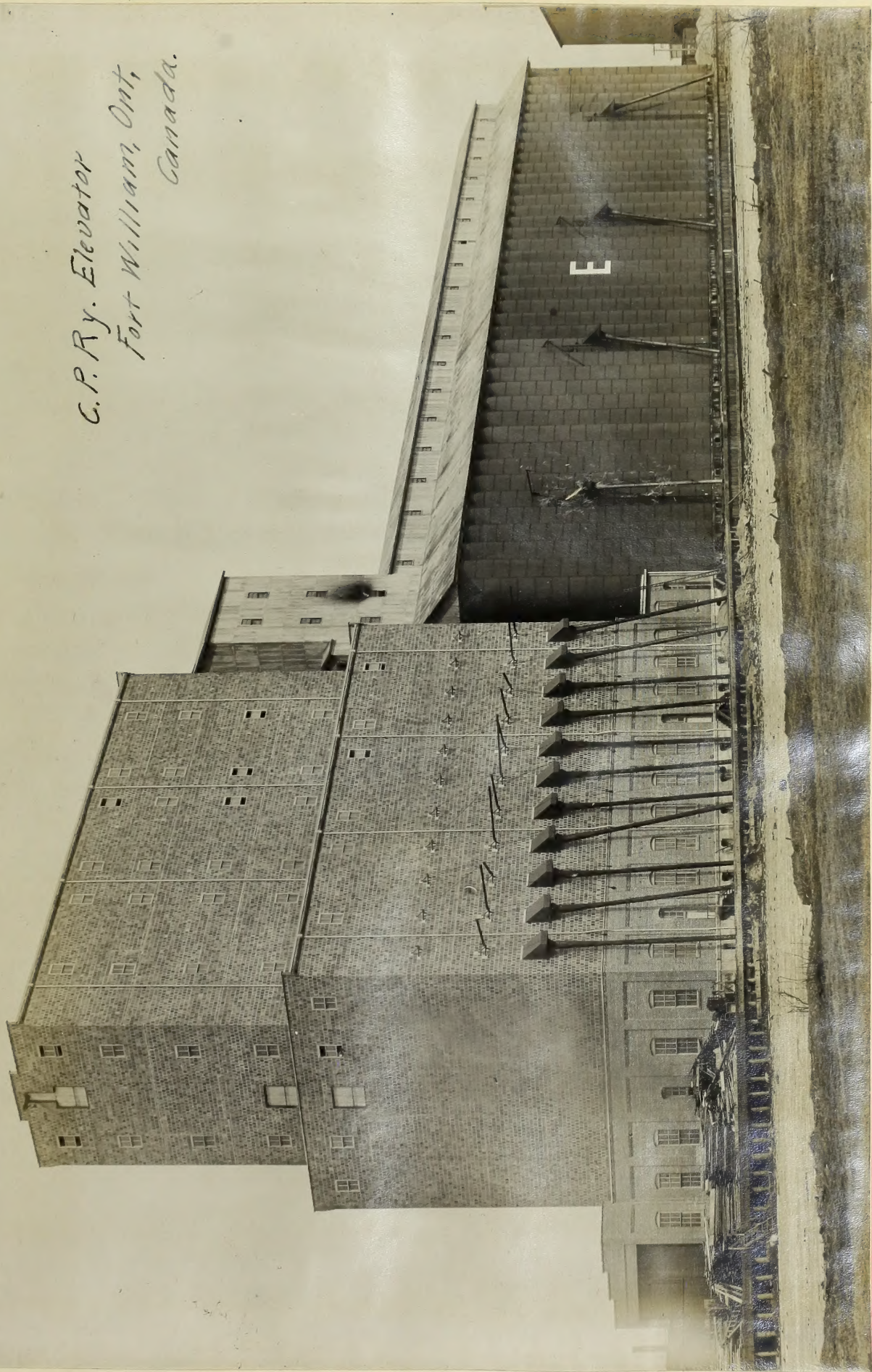
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